R&D on CSP and Solar Chemistry at DLR

Dr. Christian Sattler, Dr. Reiner Buck,
Dr. Karl-Heinz Funken, Dr. Peter Heller, Klaus Hennecke,
Prof. Dr. Bernhard Hoffschmidt, Prof. Dr. Robert Pitz-Paal

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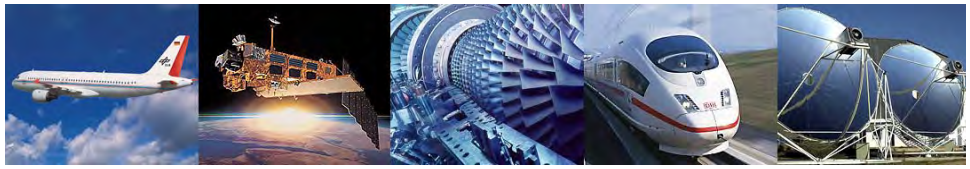
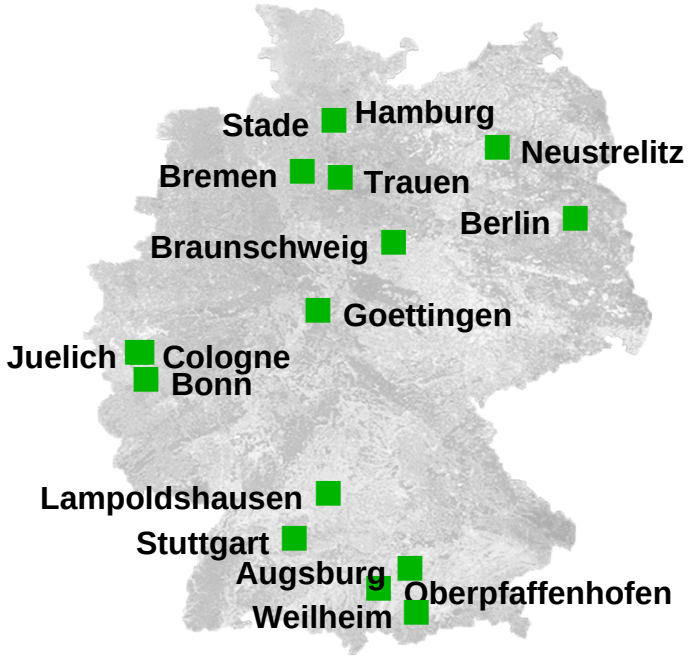
DLR German Aerospace Center

- Research Institution
- Space Agency
- Project Management Agency



>8000 employees across
32 institutes and facilities at
16 sites.

Offices in Brussels, Paris,
Tokyo and Washington, Almería.



Energy Program Themes

- Efficient and environmentally compatible fossil-fuel power stations
  (turbo machines, combustion chambers, heat exchangers)

- **Solar thermal power plant technology, solar conversion**
- **Thermal and chemical energy storage**

- Wind energy converters

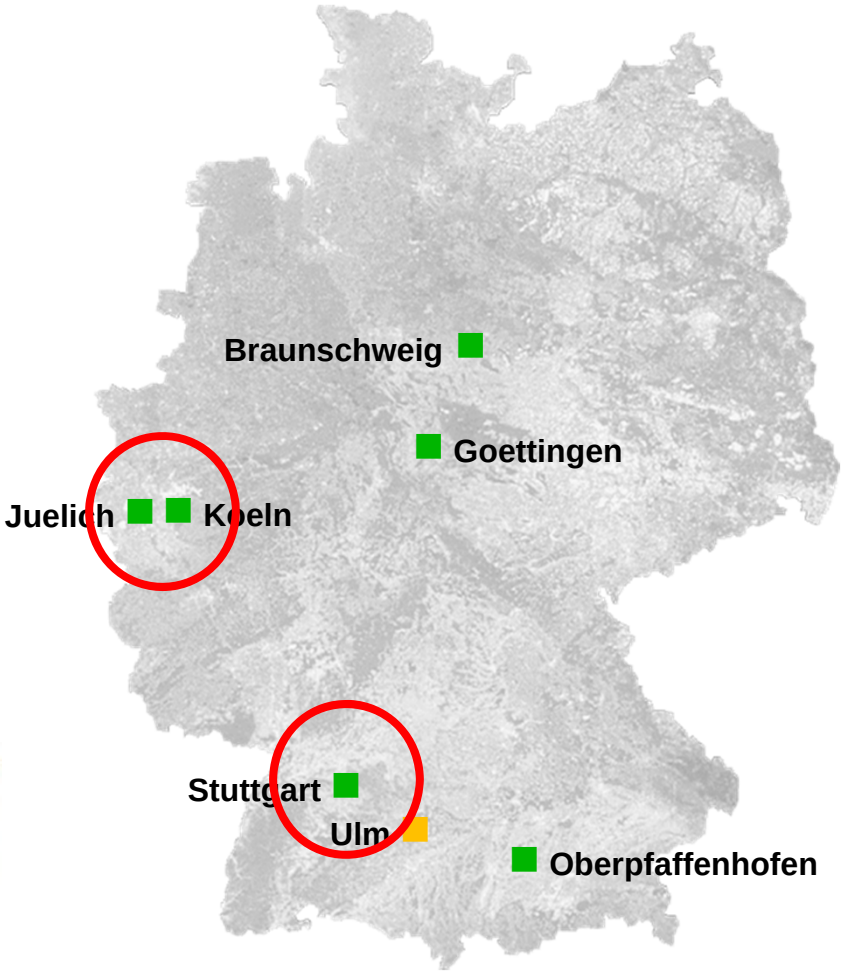
- High and low temperature fuel cells

- **Systems analysis and technology assessment**

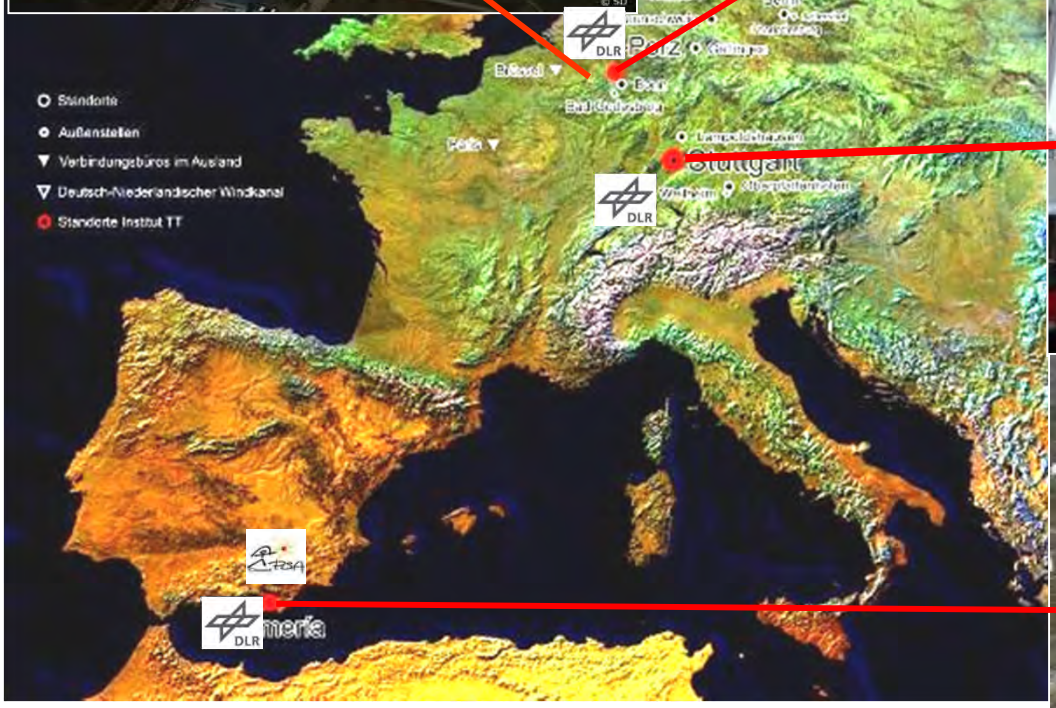
Institutes and Facilities Involved in Energy

Braunschweig
Institute of Aerodynamics and Flow Technology
Goettingen
Institute of Aerodynamics and Flow Technology
Cologne
Institute of Propulsion Technology
Institute of Solar Research
Institute of Materials Research
Juelich
Institute of Solar Research
Stuttgart / Ulm
Institute of Technical Thermodynamics
Institute of Combustion Technology
Oberpfaffenhofen
Institute of Communications and Navigation

Almería (Spain)
Permanent team from the Institute of Solar Research at the Plataforma Solar de Almería (PSA)



Institute of Solar Research



DLR

Institute of Solar Research

Directors

Prof. Dr. Robert Pitz-Paal/ Prof. Dr. Bernhard Hoffschmidt

Point-Focus Systems	Line-Focus Systems	Qualification	Solar Chemical Engineering	Facilities and Solar Materials
Dr. Reiner Buck (34 P)	K. Hennecke (16 P)	Dr. P. Heller (33 P)	Dr. C. Sattler (26 P)	Dr. K.-H. Funken (20 P)

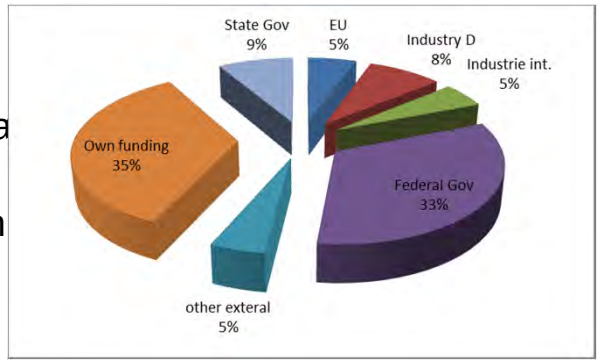




Institute Profile

Mission

- 1/3 fundamental scientific questions to enable next generation technology for electricity, heat, fuel and water using concentrating sola power
- 2/3 applied development task for/with industry to optimize products an technologies



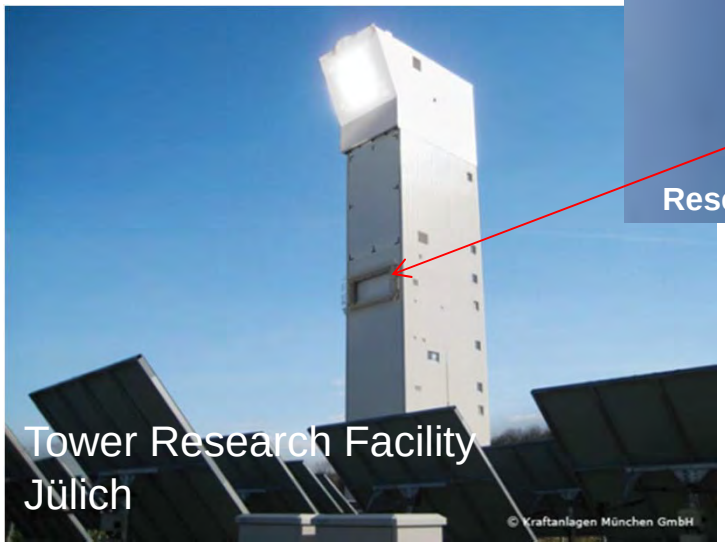
Key data

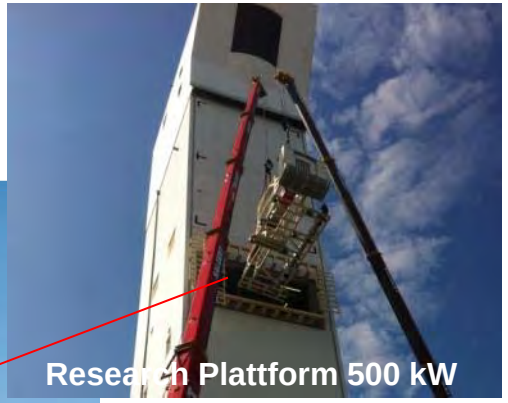
- Annual turnover >15 Mio€ (in CSP related activities)
- More than 160 people (among Top 5 worldwide)
- Teams in Germany (Cologne, Stuttgart, Jülich) and Spain (Almería)
- Unique Infrastructure
- Active coordination of national and international networks in CSP

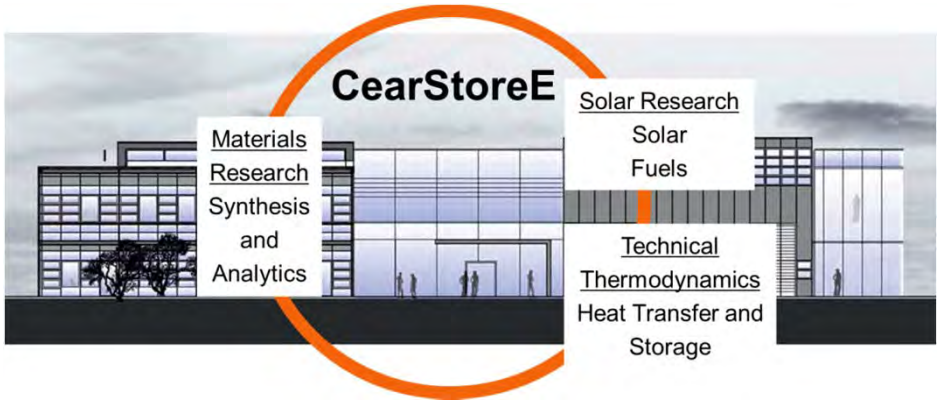
Track record

- Awarded as DLR Centre of Excellence 2006, 2009 and 2013
- Several license agreements with industry on DLR Patents (Receivers, measurement technology)
- 2 Spin-off companies founded in the last 6 years
- CSP Component Qualification Centre QUARZ™ is market reference

Large scale facilities







Department “Line Focus Systems”

Klaus Hennecke
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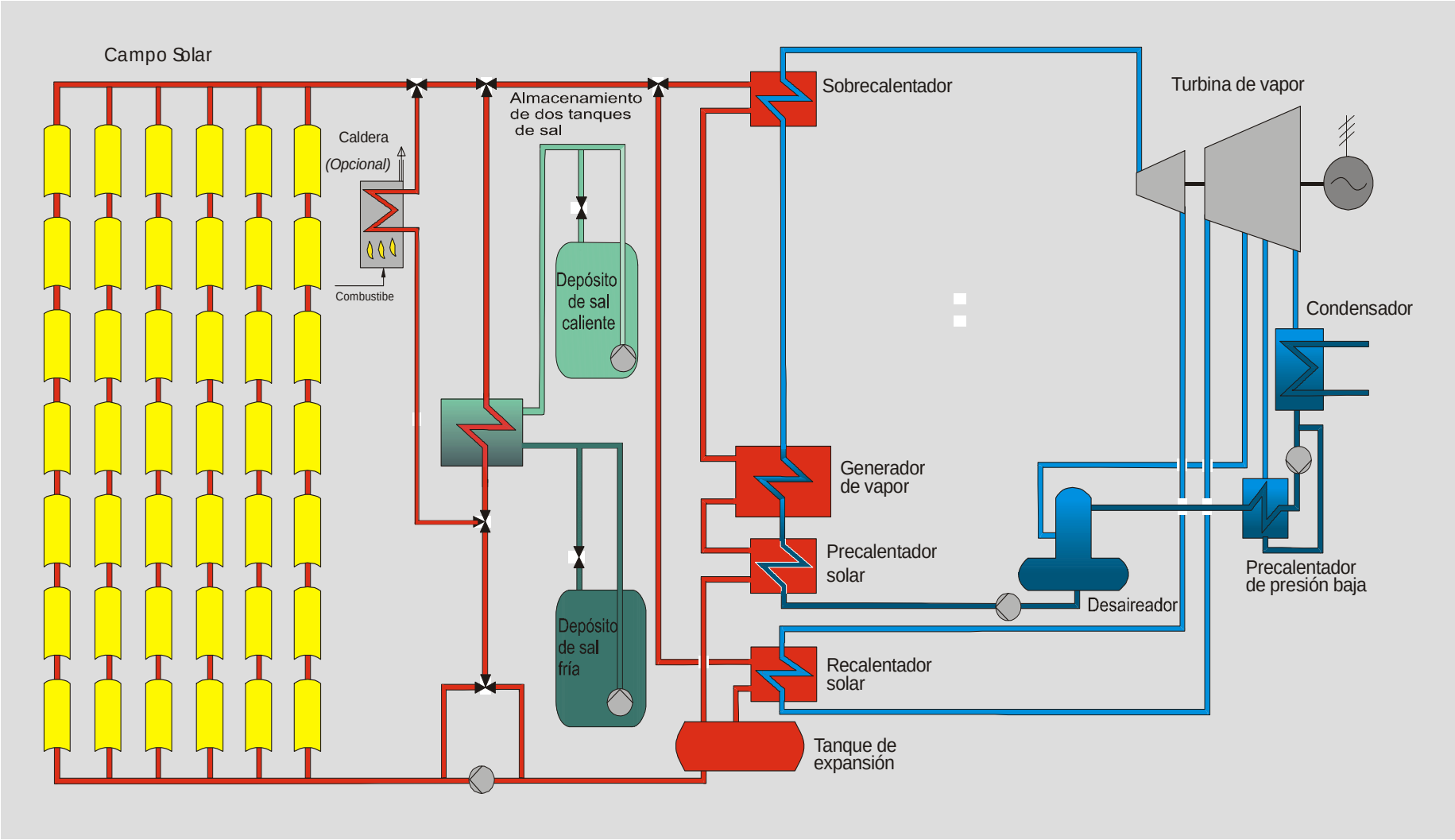
ANDASOL 1: Start of operation 2008

State-of-the-art parabolic trough power plant technology

Plant schematic Andasol (50 MW)

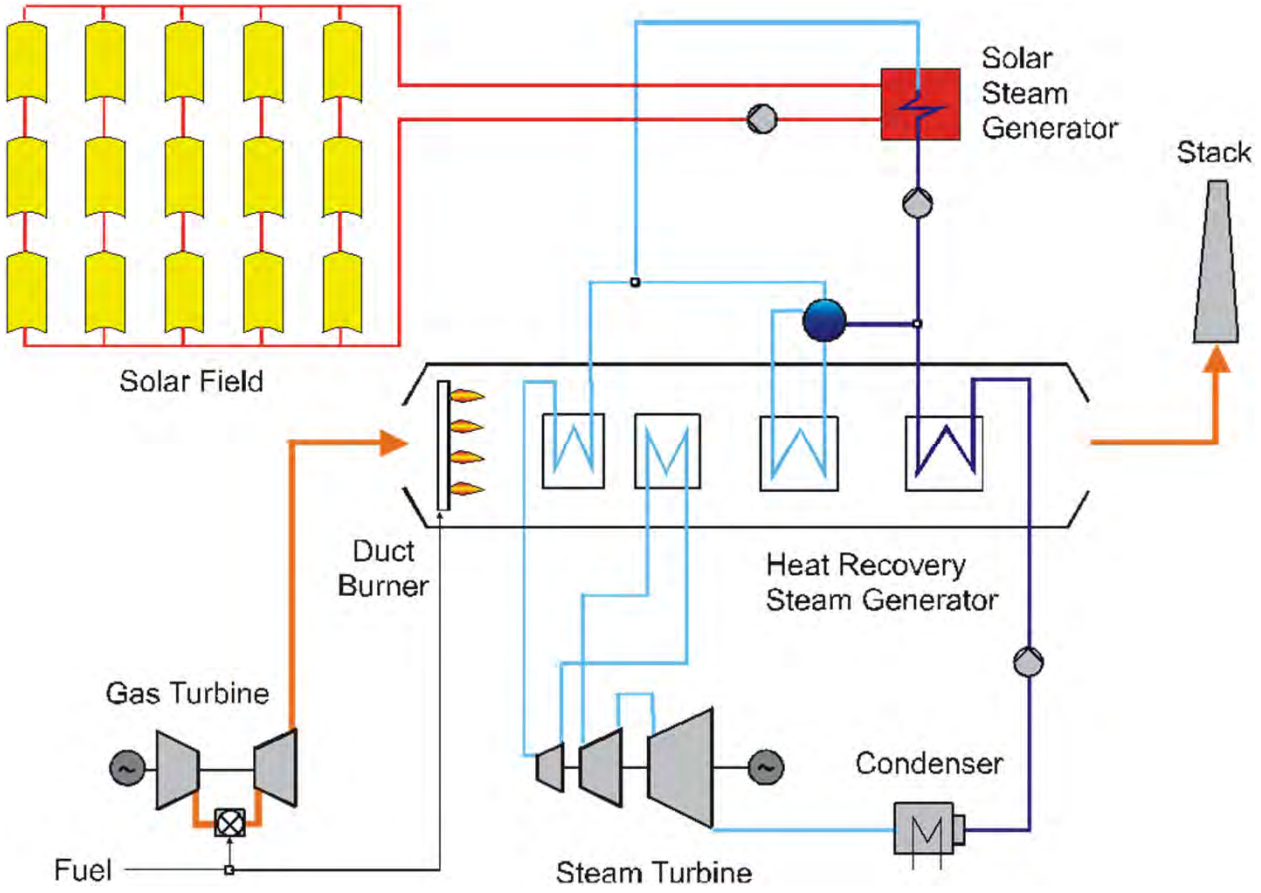


Integrated Solar Combined Cycle plant

Projects in
- Algeria
- Egypt
- Morocco
- Mexico

Solar share limited by
- solar steam parameters
- turbine ability to accept additional steam

Transition technology
- build confidence

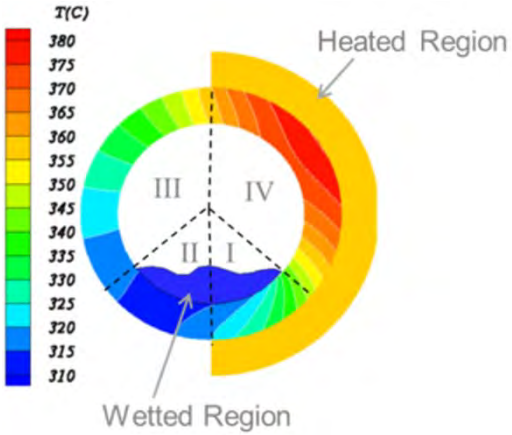


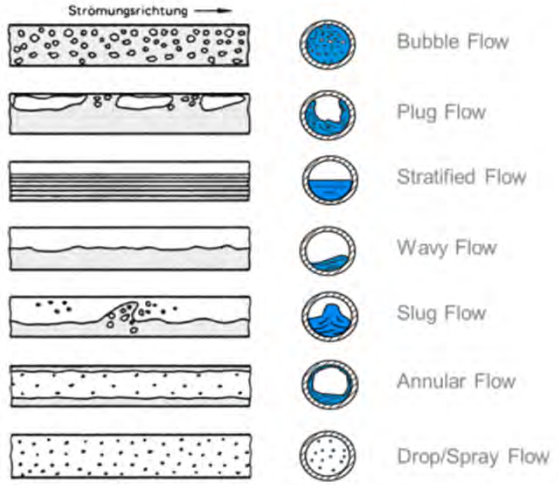
Egypt, 146 MW ISCCS, 30 MW Solar Field

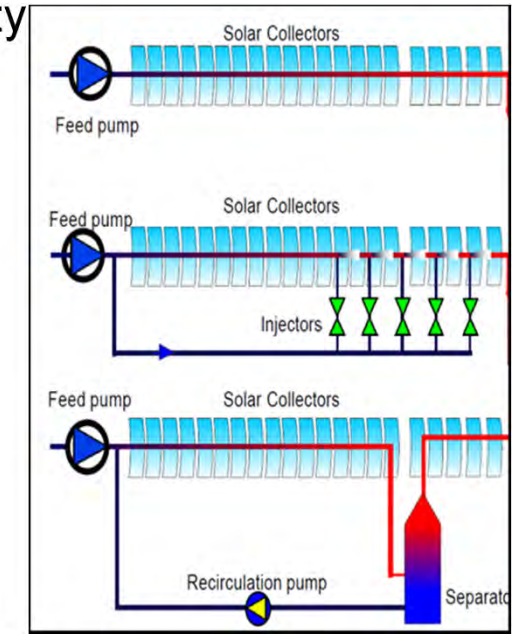
Developer NREA New & RenewableEnergy Agency
EPC financedbyJBIC and NREA with 50Mio Grant
984GWh per year, of which 64.5GWh solar
Awarded to Iberdrola (CC) and Orascom/Flagsol (Solar Field)

Direct Steam Generation Research

- Understand thermohydraulic phenomena
- Validate numerical models
- Develop and test operating concepts and control algorithms
- Test components in real scale
- Demonstrate technical feasibility
- German/Spanish Collaboration PSA DISS test facility
  1000 m collector loop up to 100 bar / 500°C







Direct Steam Generation commercial applications

- TSE1 Kanchanaburi, Thailand
  - Developer: SOLARLITE
  - Operational 11/2012
  - 5 MWe
  - 30 bar / 330°C

DLR support portfolio:

concept design

construction supervision

commissioning

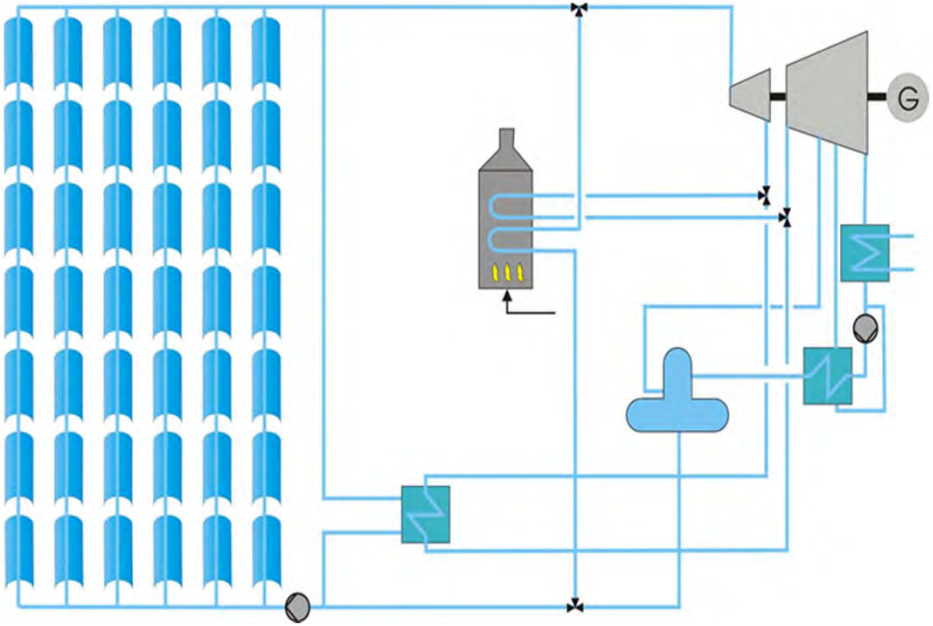
acceptance testing

- PE2 Puerto Errado, Spain
  - Developer: NOVATEC
  - Operational 8/2012
  - 30 Mwe
  - 55 bar / 270°C

Conclusions on DSG

- For short to mid-term, technology ready for :
  - CSP plants without or with small storage
  - Integrated Solar Combined Cycle (ISCC) or fuel saver plants
  - Industrial process steam applications

- For long term DSG perspective, R&D requirements:
  - Development of economic PCM storage system
  - Development of once through process (DUKE Project at PSA)



Molten Salt R&D: HPS2 Project

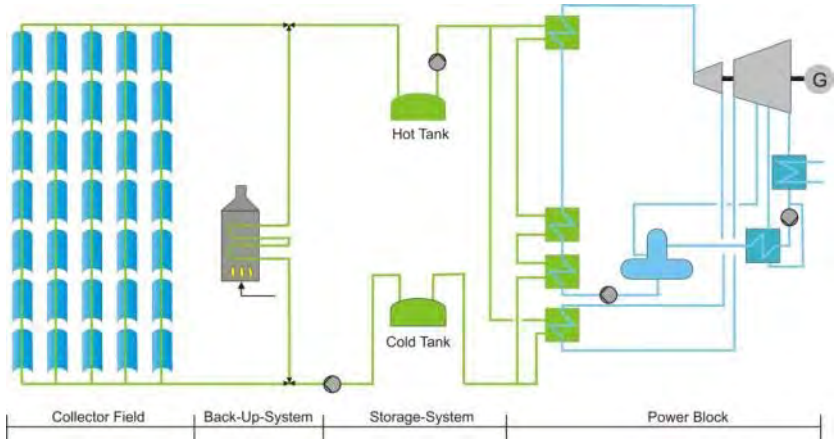
10 main concerns regarding safe and efficient operation of molten salt systems to be dispelled by erection, commissioning and operation of a Demonstration Loop with Ultimate Trough collectors at Évora, Portugal:

1. Filling and draining of the plant
2. High thermal effort during anti-freeze operational mode (high parasitic load, added costs for the required heating through the year)
3. Danger of freezing during various operation modes (reliability of impedance heating, failure current of impedance heating, valve heating, …) 4. Blackout scenarios
5. Material requirements, high corrosion
6. Performance of the SCA (receiver performance, Behavior of receiver with collector) a. thermal performance, b. optical performance, c. mechanical properties
7. Flexible connection: Proof of functionality and tightness
8. Steam Generating System: internal leakage due to defect of heat exchanger tubes
9. Maintenance procedures, Handling of disturbances (complete draining and re-filling, treating of blockages)
10. Stability of salt mixtures (time stability, thermal stability)

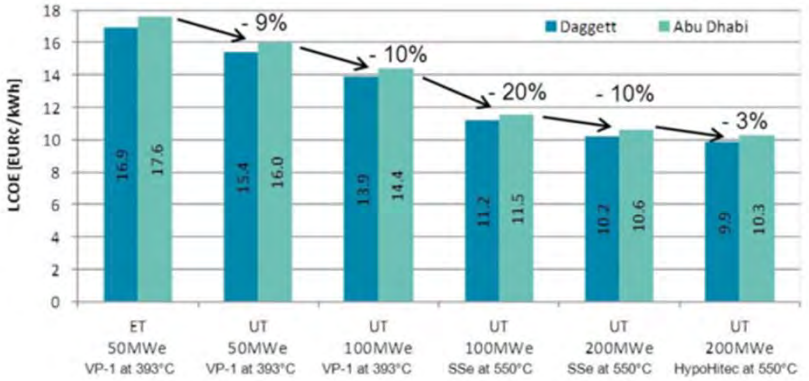
Parabolic Trough Power Plant with Molten Salt

Advantages

- High efficiency of the solar collector at high operating temperature
  => high overall efficiency of the power station
- Direct storage of the collected heat
- Full-decoupling of the solar field operation and the electricity production
- Commercial plants with capacity factors of over 5500 full load hours
- Potential to save up to 40 % of LCoE in comparison to state-of-the-art solar thermal power stations (at highly irradiated locations)
- 100 % renewable and fully storable energy



Schematic figure of Molten Salt based STPP



LCoE evaluation over technologies

Overview of DLR CSP simulation tools

- DLR simulation tools cover all levels of CSP simulation

GREENIUS: analysis of performance / economics of renewable energy systems

ebsSolar®: detailed performance analysis of CSP systems

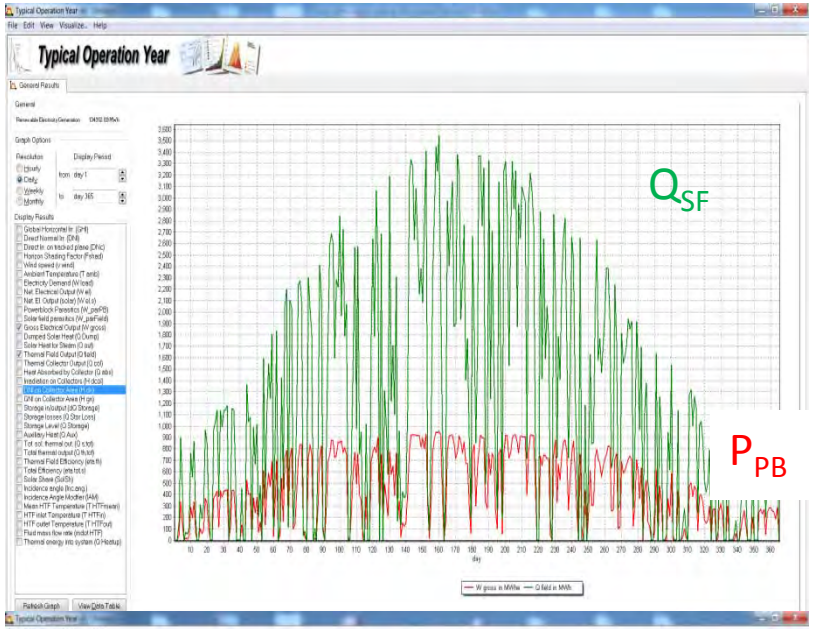
component layout:
- concentrators (parabolic trough, Fresnel, heliostats)
- receivers

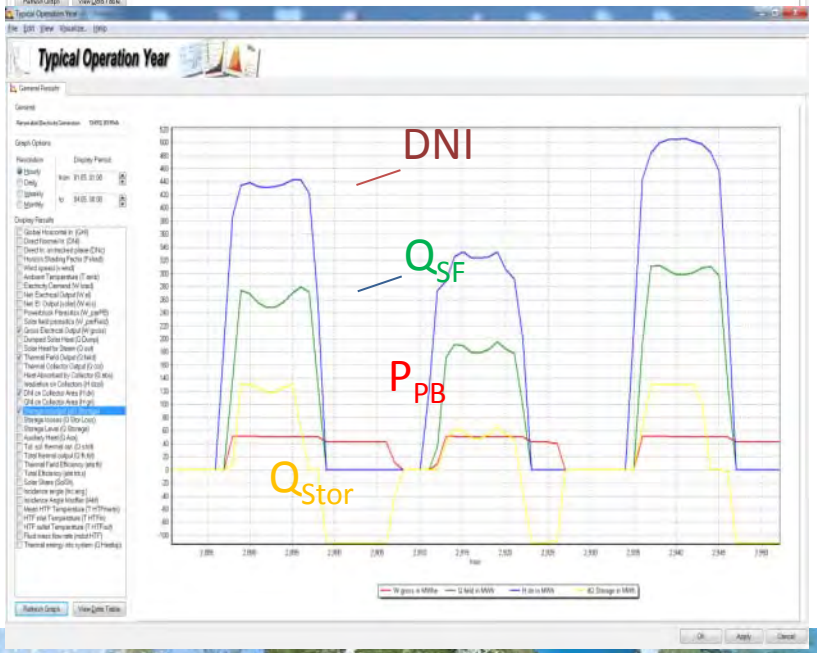
system layout optimization:
- solar field, receiver
- power block
- storage

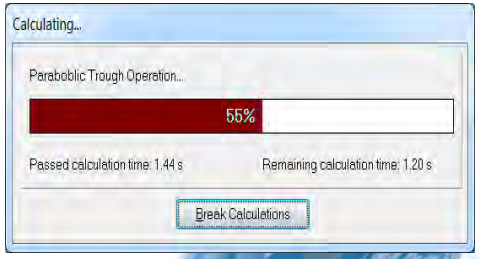
transient system simulation:
- real-time, high resolution performance simulation
- coupling of components and control

Greenius Overview

- software tool developed at DLR for fast and simple annual performance calculations of renewable energy plants
- based on datasets for individual subsystems like collector, solar field, powerblock, etc.
- uses steady-state simulations in hourly time steps
- offers tools for economical analysis and illustration of result
- a free version is available at www.FreeGreenius.dlr.de

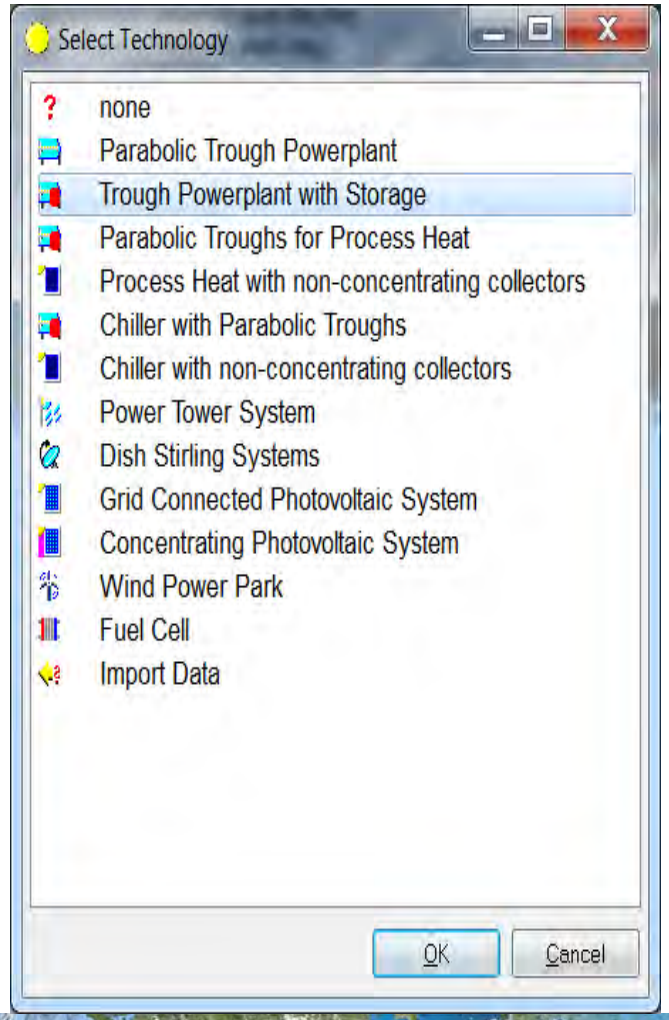






1. Greenius
Implemented technologies

- most renewable energy systems
- CSP:
  - parabolic trough
  - linear Fresnel
  - solar tower
  - Dish Stirling
  - optional: thermal storage
- process heat generation
- solar cooling with absoption chillers
- PV and concentrating PV
- wind turbines
- fuel cells



Detailed System Performance Simulation

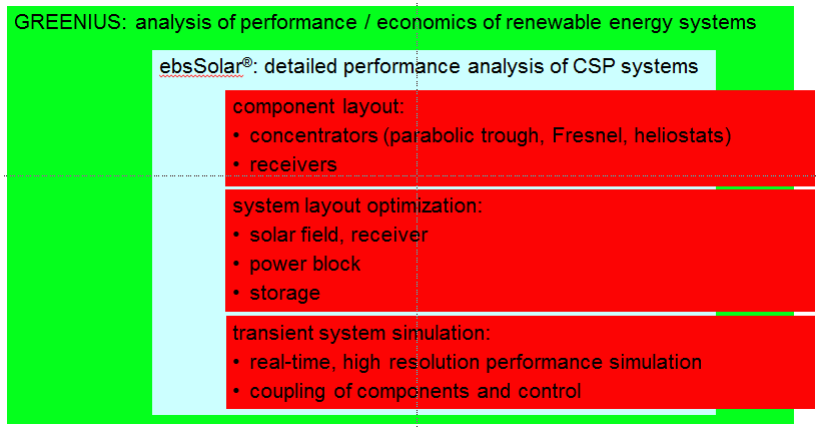
using Ebsilon®

- „All in One" solution for detailed power plant modelling
- for development, acquisition und planning
  of all kinds of power plants and thermodynamic processes
- design and development of single components, subsystems and complete systems
- development of new solar library EbsSolar (steag and DLR):
  - thermodynamic modelling and yield analysis (e.g. annual yields)
  - components of solar thermal power plants
    (Dialog for time series calc., transient calc. for energy storage, fluid properties for solar applications)
  - 2010: library for line focussing systems
    - Parabolic Trough
    - Linear Fresnel
  - 2011: library for Solar Tower systems
  - currently more than 70 licences of EbsSolar are used

Summary / Conclusion

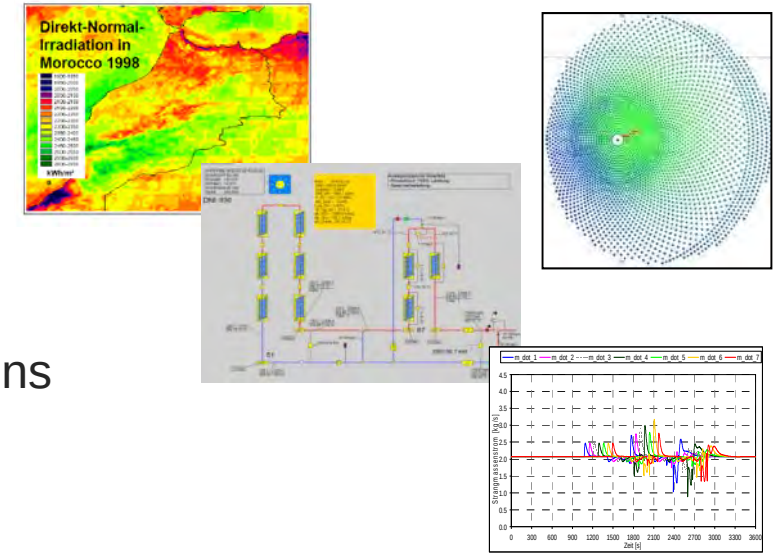
DLR simulation competence

- covers all levels of detail
- cover all CSP technologies
- coupling of different tools
- collaboration experience with industry and R&D institutions



Options for collaboration

- technology-independent consulting
- subcontracted work
- joint development of tools
- adaptation of tools specific tasks and conditions
- licensing of tools, incl. training and support



Department “Point Focus Systems”
Thematic Orientation

Goal: Cost Reduction of CSP Plants (Solar Tower, Dishes)

- performance optimization
  - heliostat field, receiver, system
- cost reduction
  - component cost, O&M cost

R&D topics:

- receivers
- heliostats
- system aspects
- control
- simulation tools

Contact:
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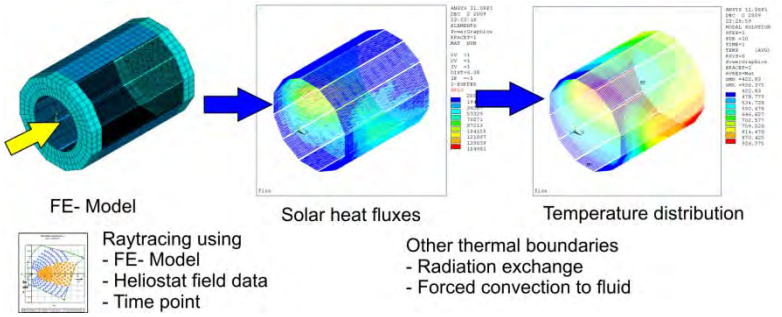
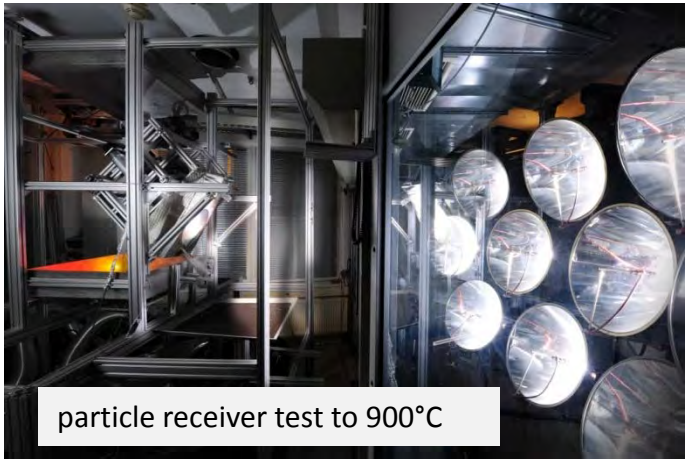
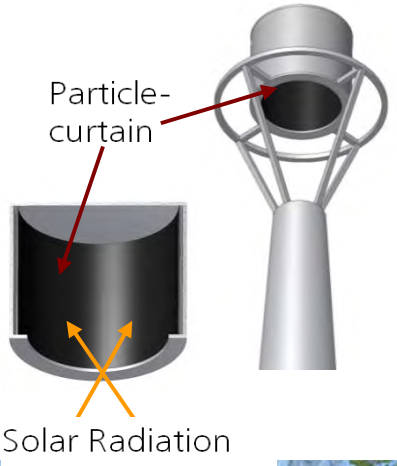
reiner.buck@dlr.de

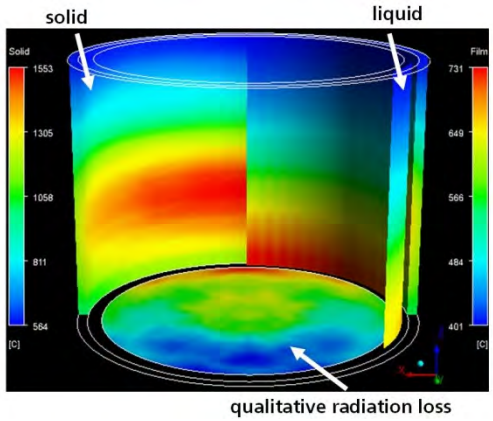
Receiver Technology R&D

- development / technology transfer
  - open volumetric air receivers
  - pressurized air receivers
- extension to liquid heat transfer media
  - e. g. molten salt
- innovative concepts: direct absorption receivers



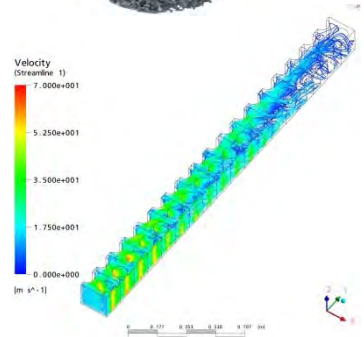

particle receiver test to 900°C

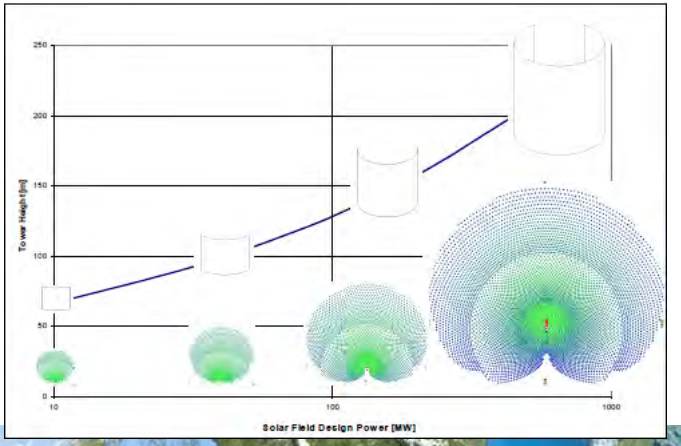




Open Volumetric Air Receivers

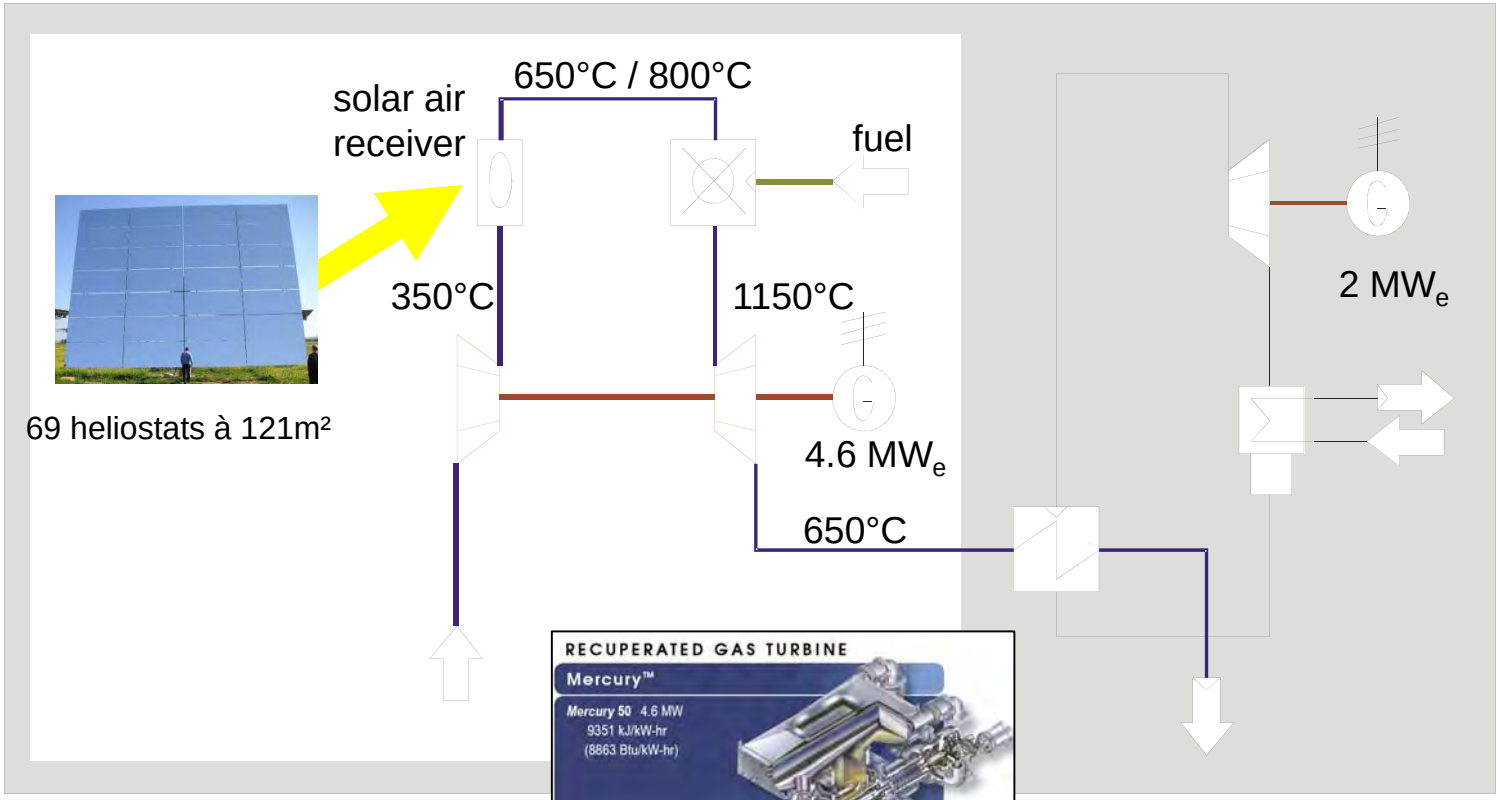
- development of volumetric absorber structures
- optimization of air receiver system
- support of commercial realization
  - development of scalable designs
  - layout of prototype plants
  - know-how transfer to industry





SOLUGAS: Solar-hybrid Plant Demonstration

co-funded by the EC under FP7



project lead: Abengoa

SOLUGAS Project: Solar-hybrid Gas Turbine System

Abengoa
Solar Power Plants,
near Seville, Spain

DLR

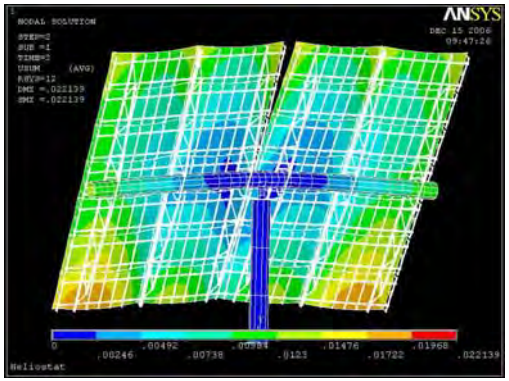
Solar Tower with Molten Salt

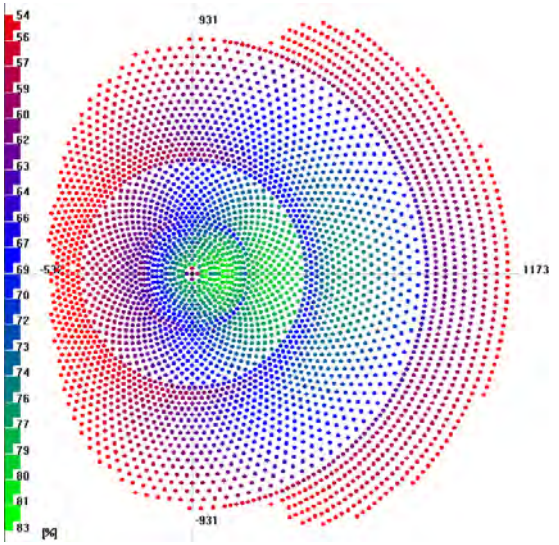
Improvement of molten salt solar tower systems

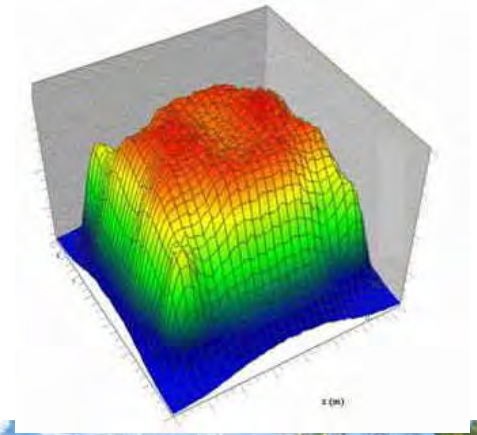
- next generation technology:
  - increased HTF temperature
  - higher power block efficiency
  - reduced LCoE
- industry participation
- tests planned at
  Solar Tower Jülich

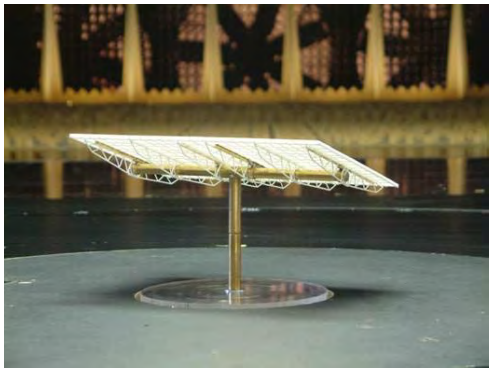
Heliostat R&D

- heliostat and field simulation
- structural analysis
- load analysis
- qualification
- control
- operation strategy



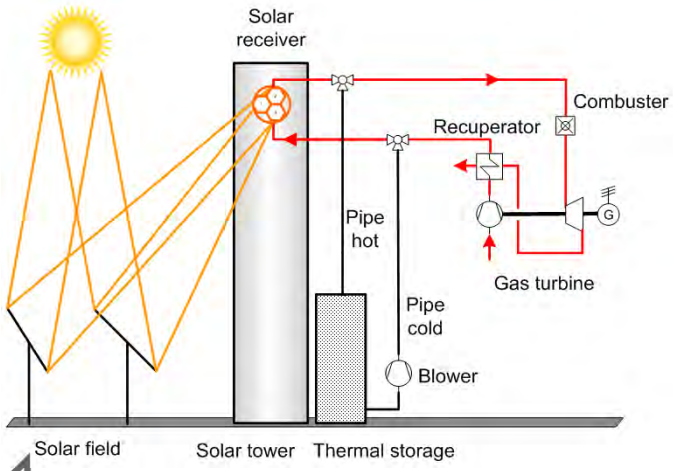


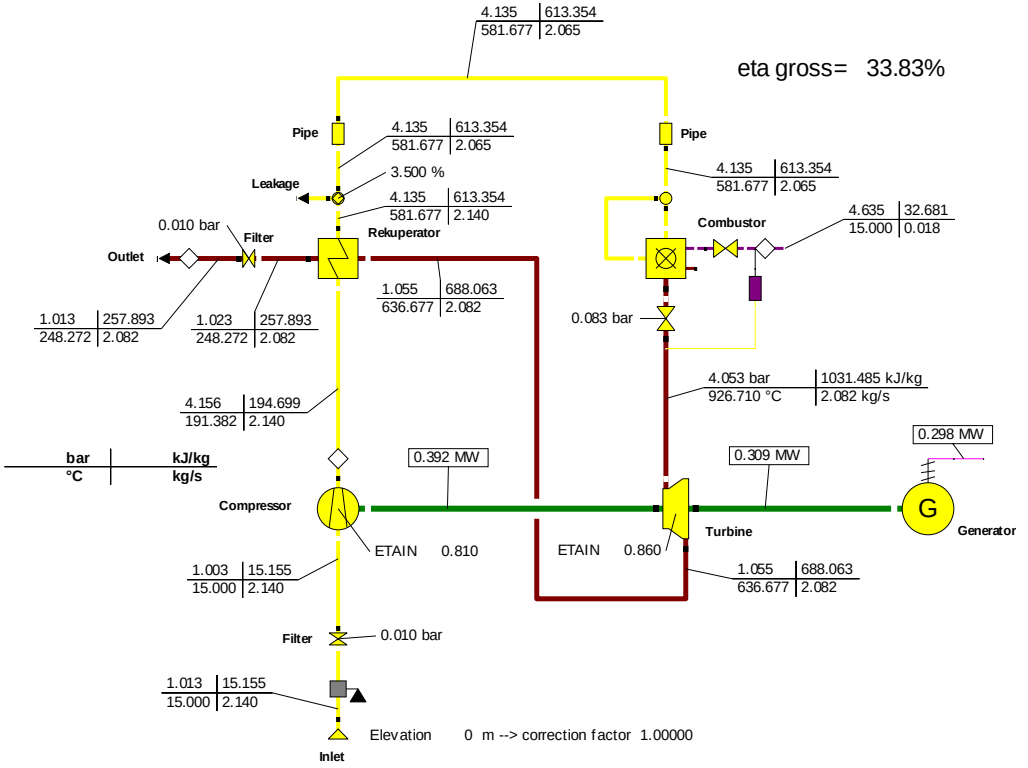




System Analysis and Optimization

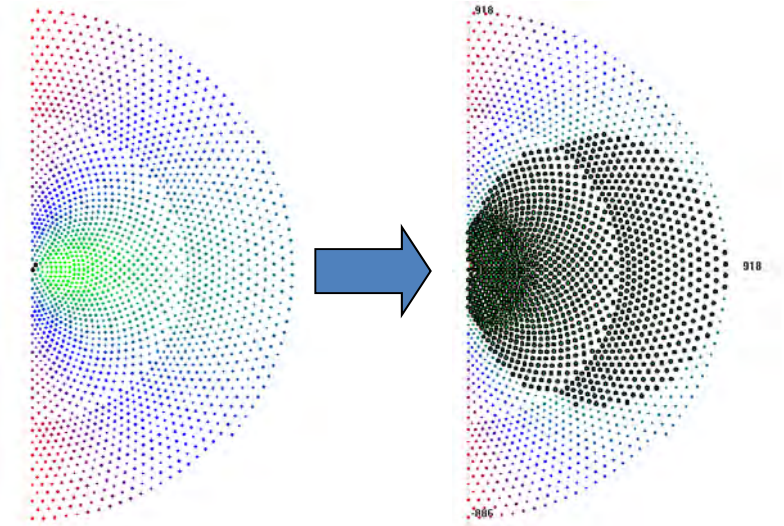
- pre-feasibility studies
- detailed annual performance simulation
- cost estimates
- LCoE calculation



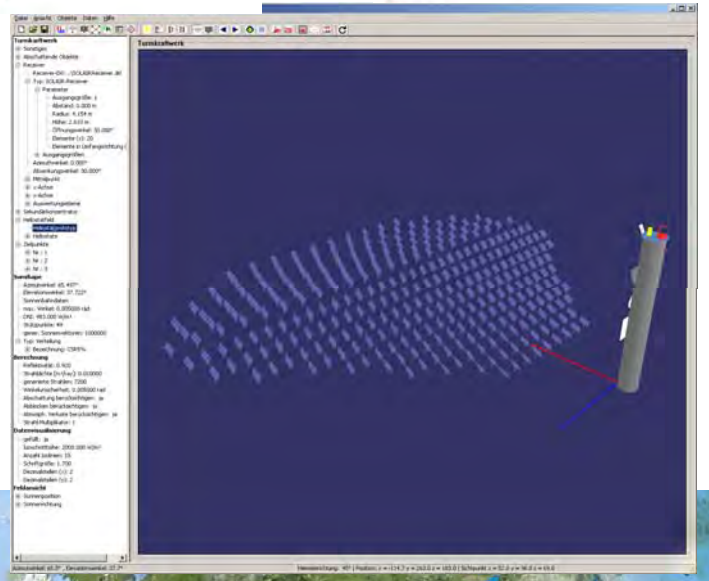


Simulation Tool Development
for Solar Tower Systems

- heliostat field layout



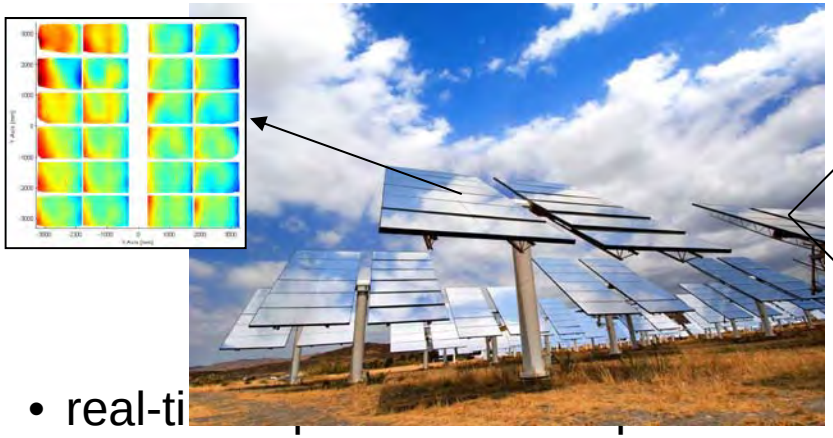
- performance simulation
  - flux distribution
  - aim point strategy
  - efficiency



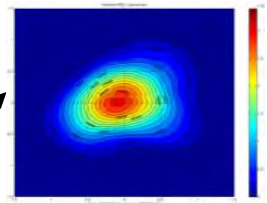
Simulation Tool Development
for Solar Tower Systems

- heliostat field analysis

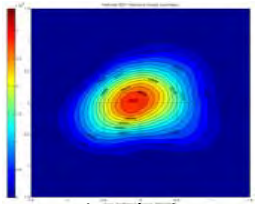
measured heliostat surface



solar heat flux

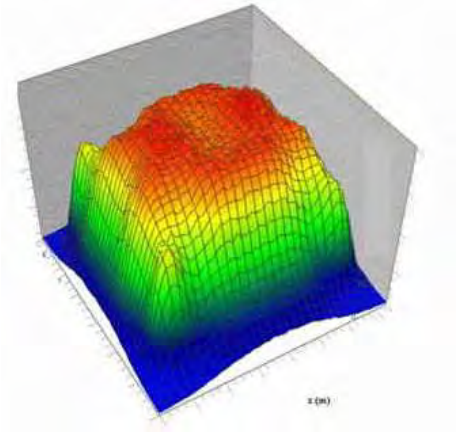


measurement

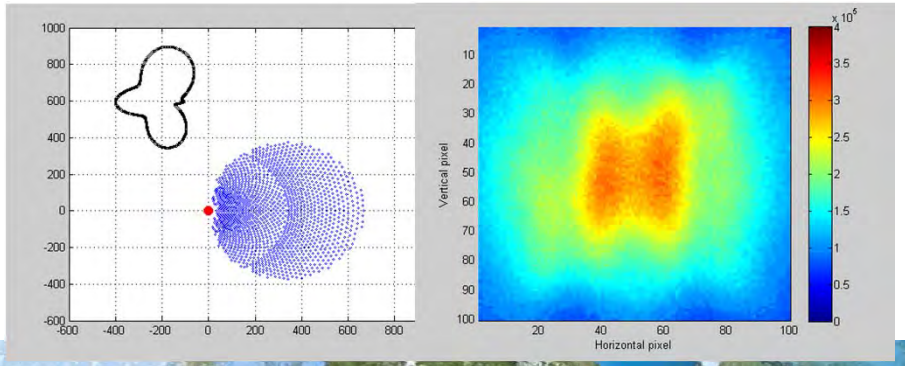


simulation

aim point strategy



- real-ti
  strategy
  - dynamic field simulation
  - dynamic receiver simulation



Department of "Qualification"

Motivation: Qualification for Improved Performance

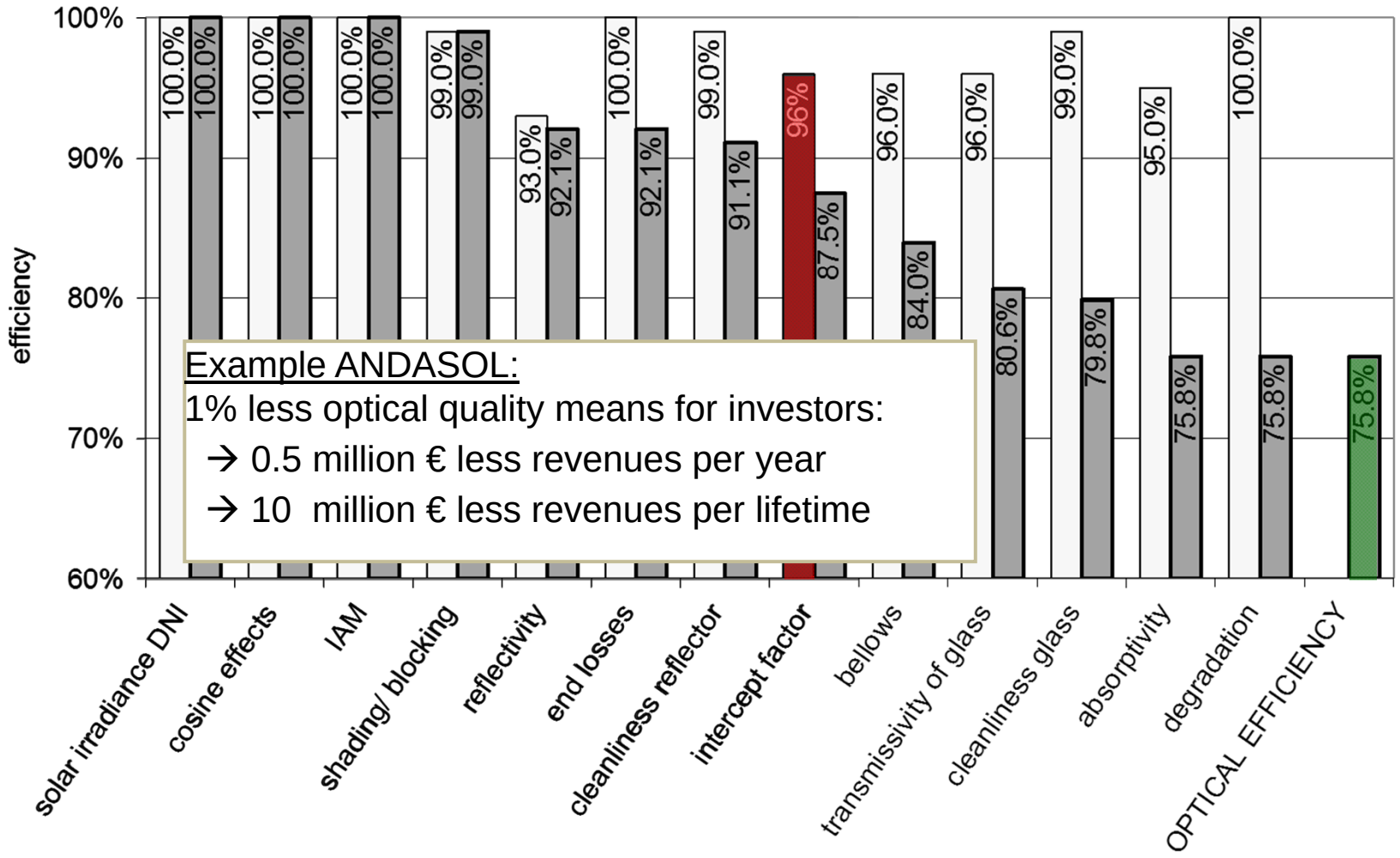
Contact:
Dr. Peter Heller
peter.heller@dlr.de

- Solar field has a high share of the total investment
- It is a *long-term* investment
- It is of *big extent* (corrections are expensive)
- Yearly *plant output* strongly depends on optical quality of collector field
  - Measurements showed that without proper quality assurance *3-10%* and in some cases even more of the field performance can be lost
- *Quality assurance* and *final acceptance tests* of collector fields are necessary for control of subcontractors and warranty claims

➔ **Quality assurance of collector field assembly is indispensable and makes economic sense**

Motivation

Efficiency Chain, Example: Parabolic Trough



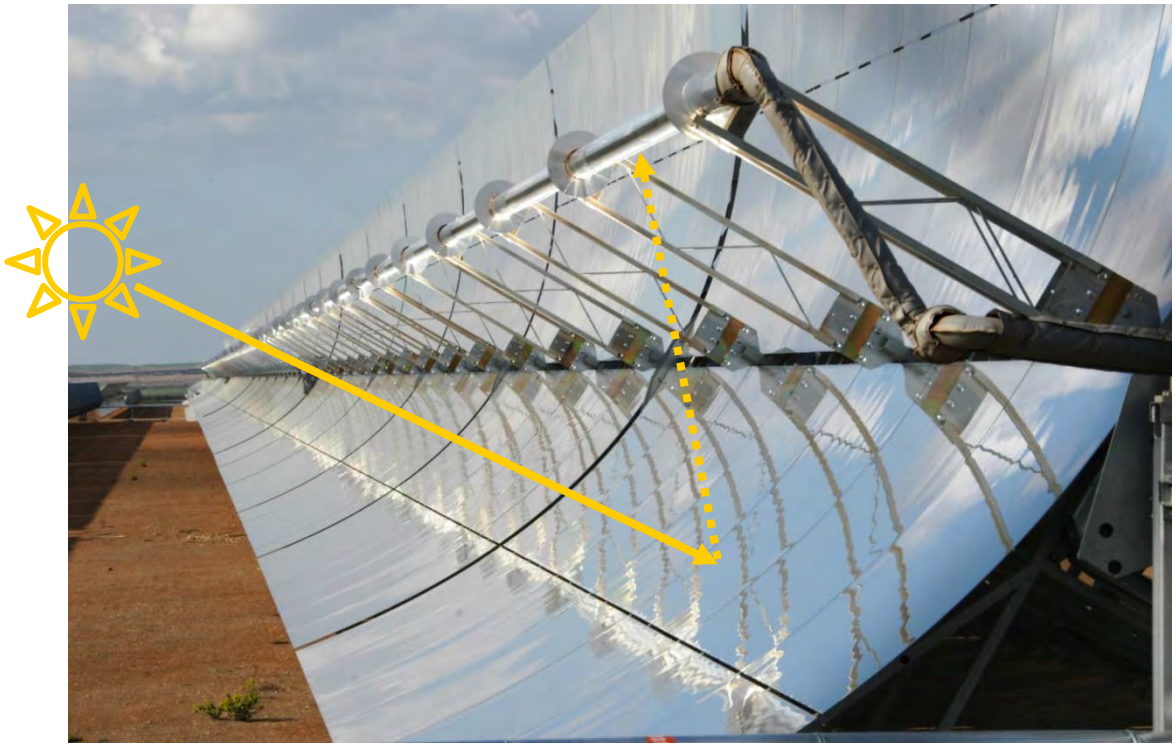
QUARZ® – Center
Test and Qualification Center for CSP Technologies

- Strong impact on the **performance and cost efficiency**:
  - CSP component quality and durability
  - their interaction in the overall system
  - and the meteorological conditions each

- Development of **measurement techniques and devices**
- Evolution of **guidelines and standards**
  - testing methods
  - quality criteria

- Customer oriented services
  - → Fundamental information for industry to
    - **Improve** quality, performance → **competiveness**
    - **Proof** of product quality → successful **market entry / bankability**
  - → Consulting and training

Solar Resource Assessment



Measurements:
- Solar Radiation
- Soiling of components
- Aerosols
- Beam attenuation, Extinction
- Sunshape
- Nowcasting (prediction of DNI for next 30 min.)

Services:
- Calibration of sensors
- Analysis of effects on Plant design, Operation, System performance

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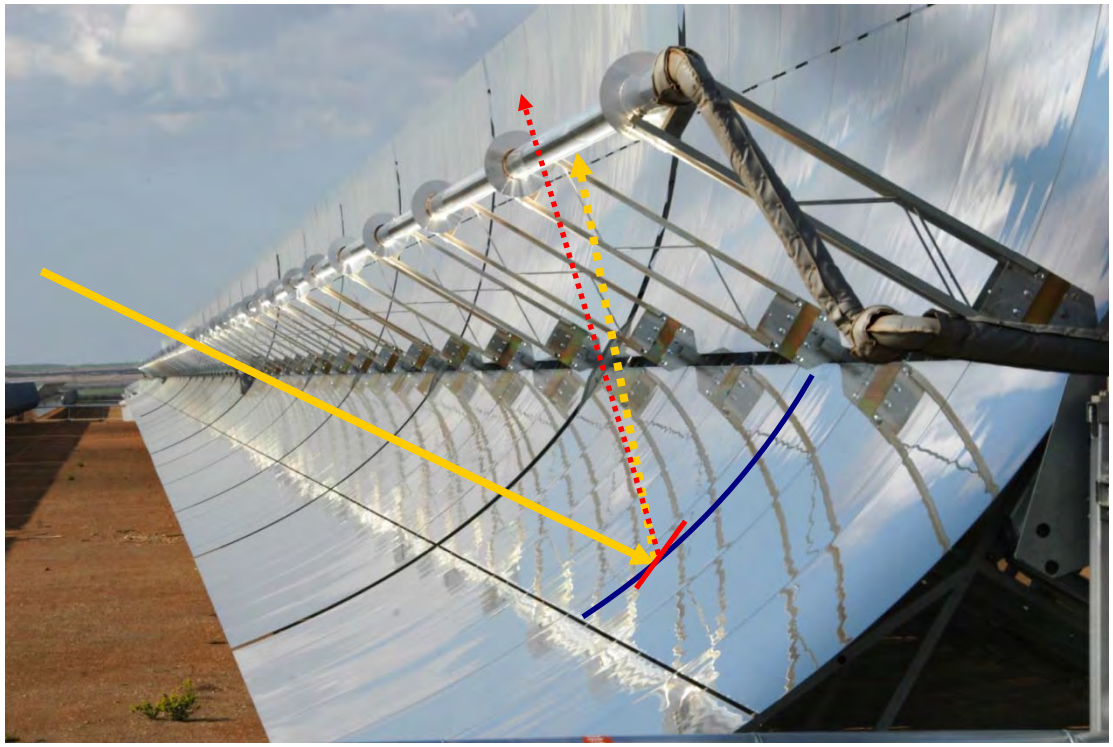
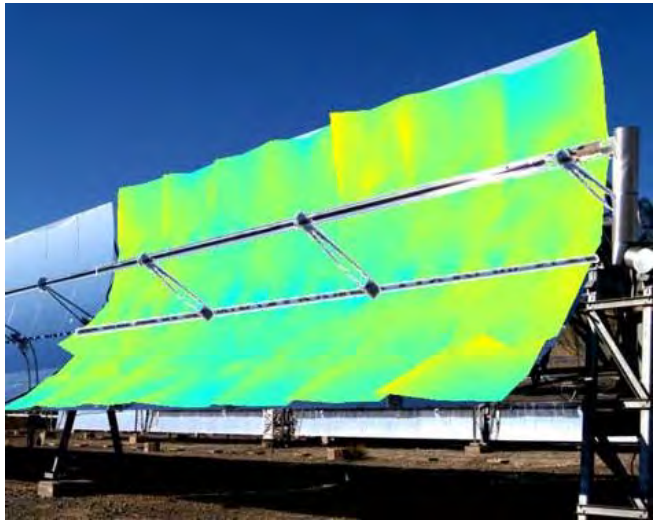
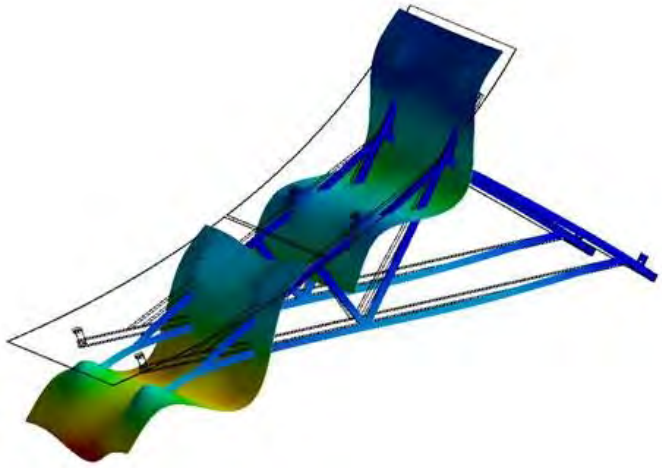
Mirror / Collector Shape Accuracy



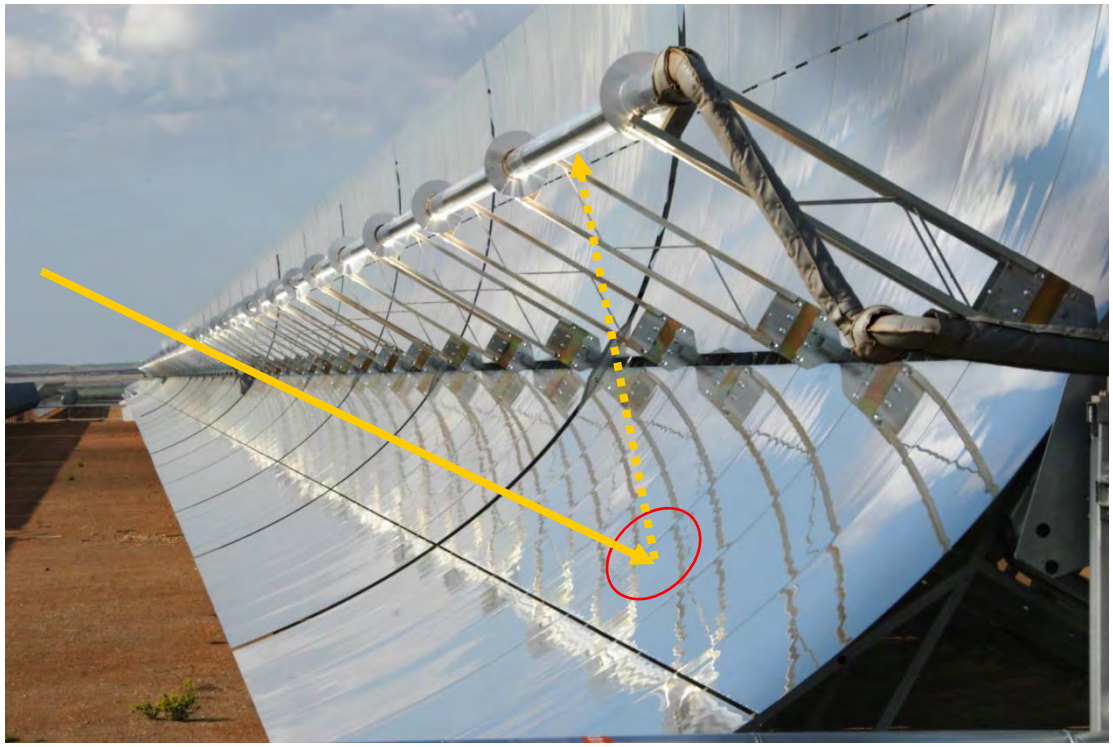


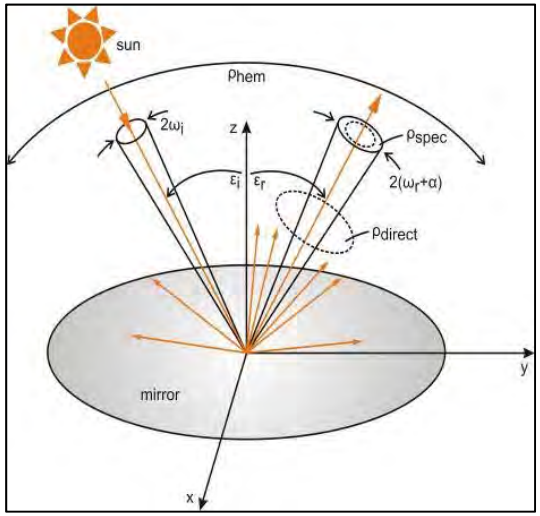


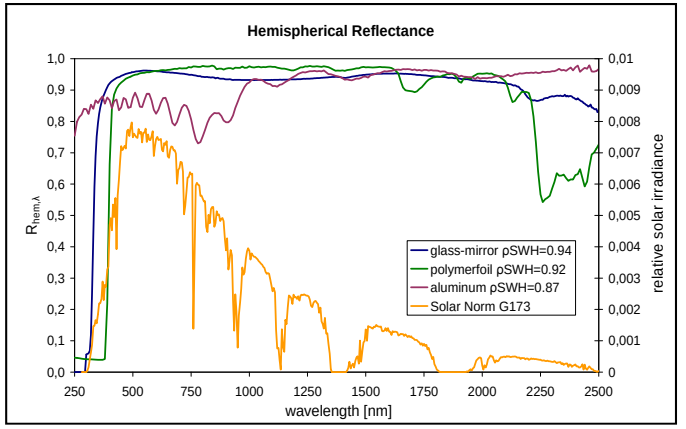
Evaluation of quality and performance parameters:

- Methods: deflectometry, photogrammetry
  (in laboratory, in the collector, in the solar field)
- Analysis of reflector deformation
  (sag, interaction with support structure)

Mirror Reflectance



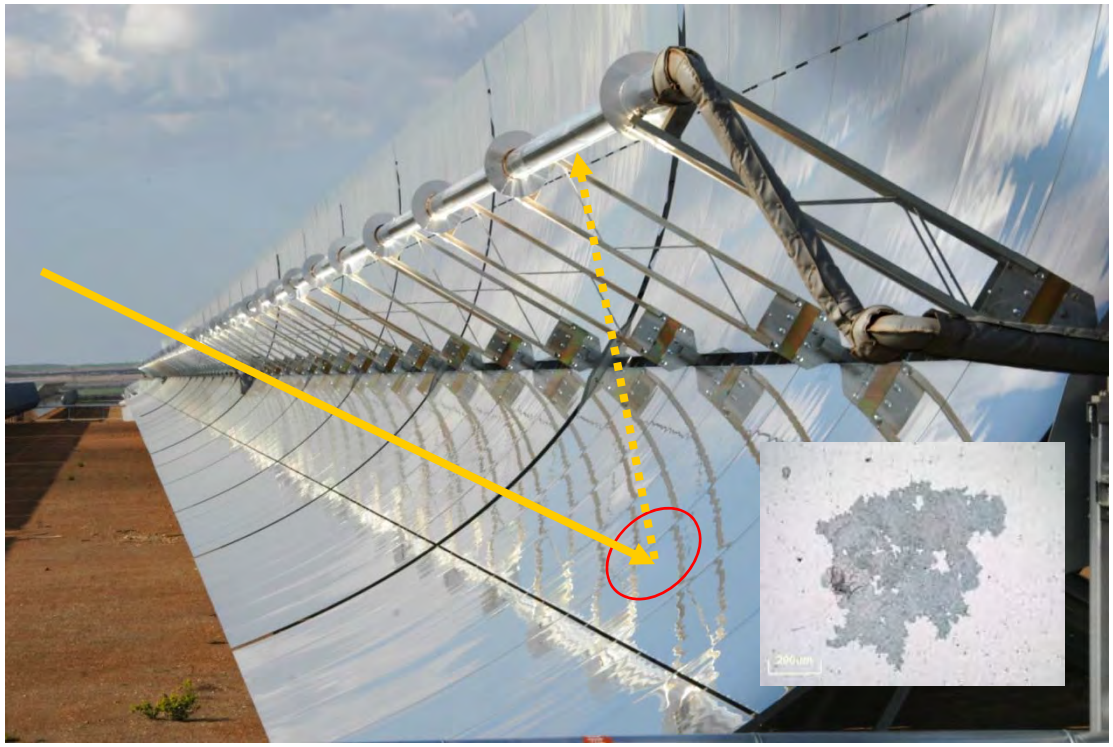




Evaluation of quality and performance parameters:

- Spectral hemispherical reflectance
- Specular reflectance

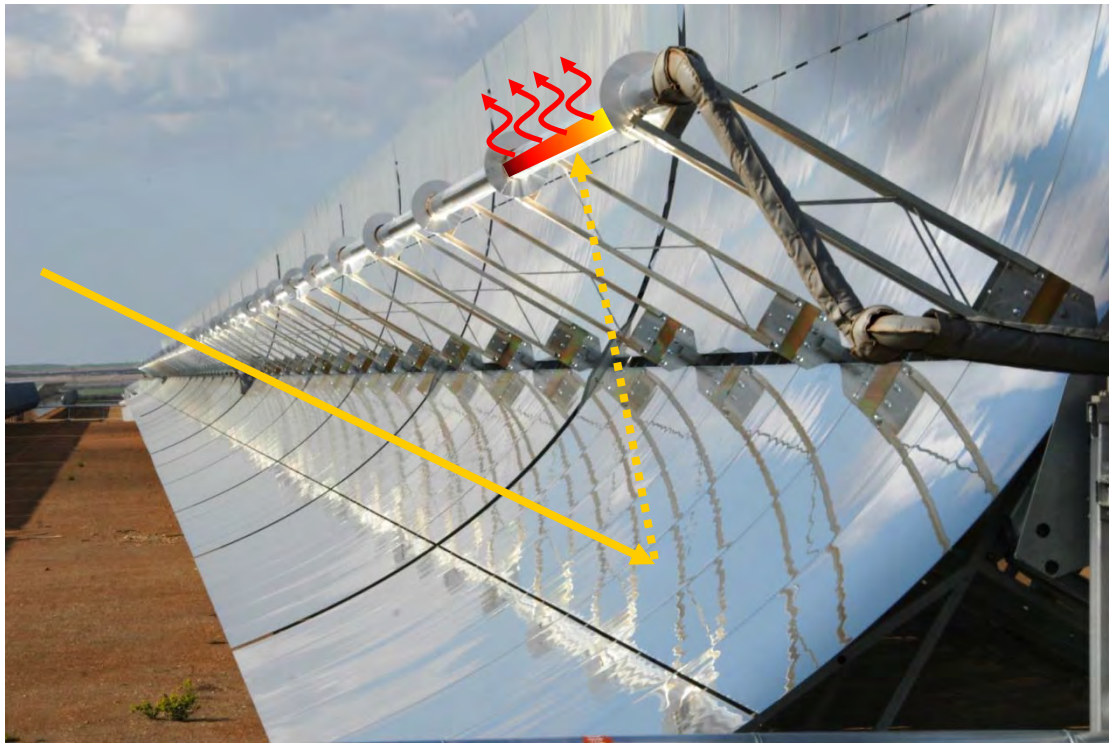
Mirror Durability

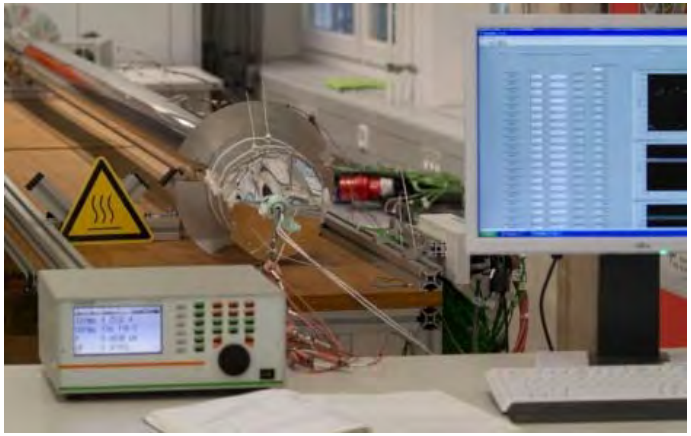


Accelerated ageing tests

- Laboratory: humidity, salt spray, UV, temp. cycling, aggres corrosion
- Outdoor ageing tests in different climatic regions

Receiver Performance



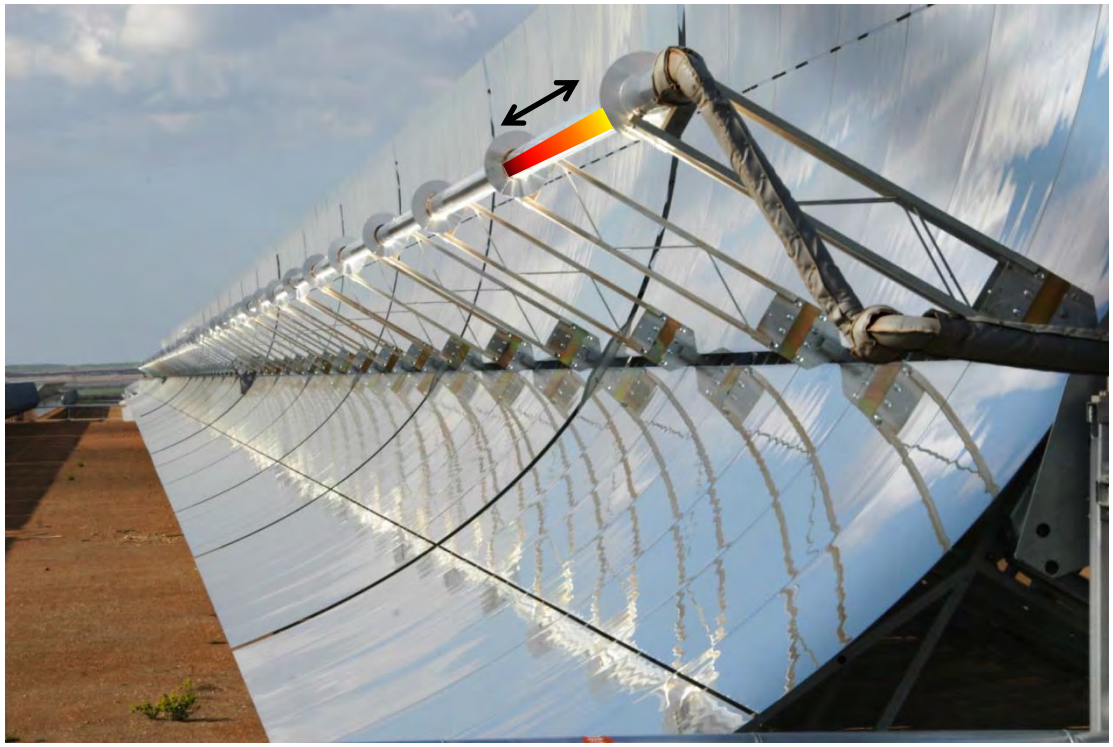


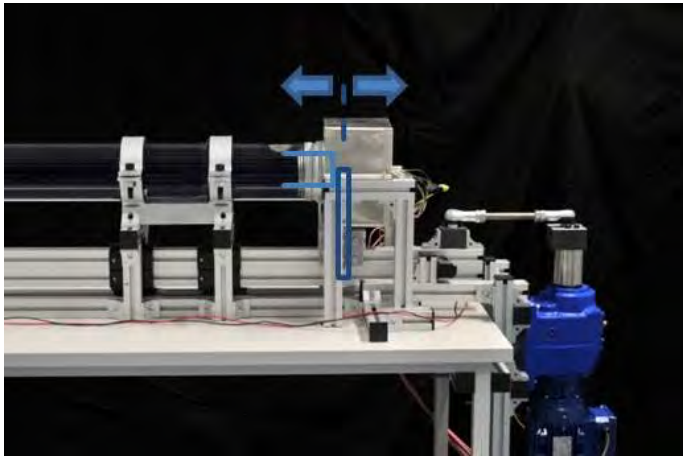
Receiver performance parameters:

- Optical efficiency $\eta_{opt,rec}(T)$
- Thermal loss power $P_{th,loss}(T)$

(non-destructive measurements)

Receiver Durability

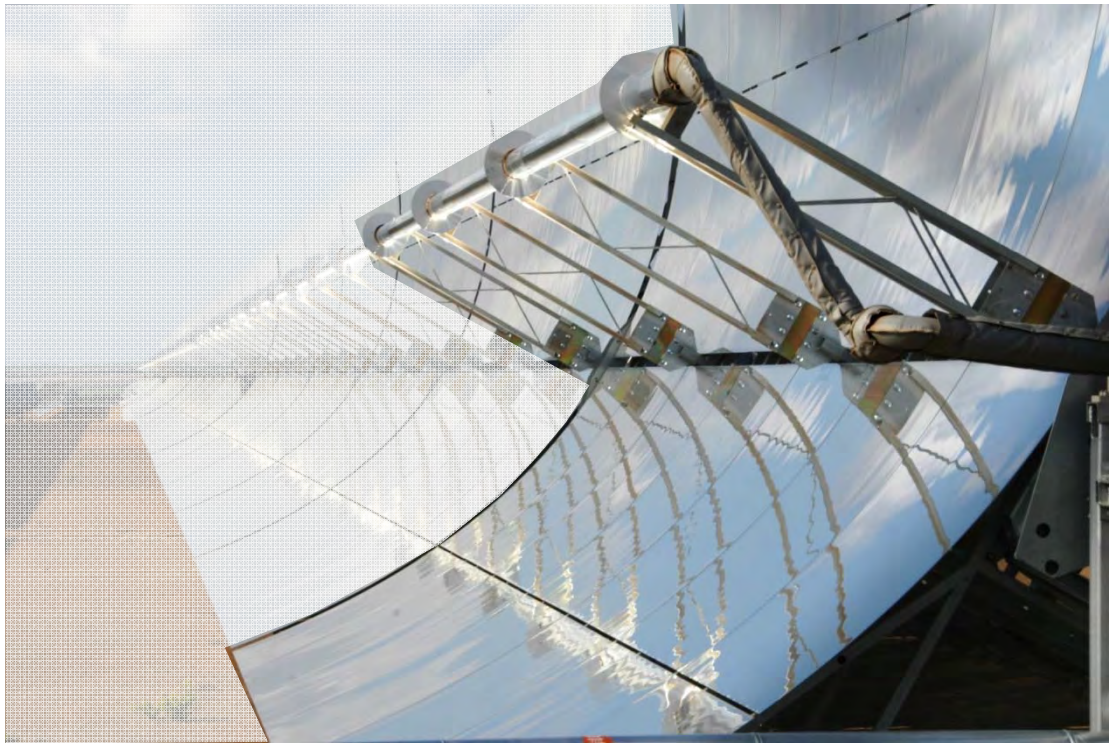


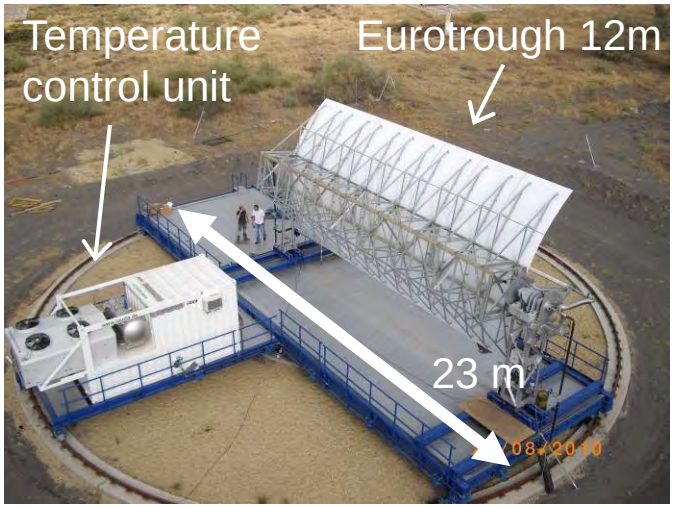


Durability tests:

- Overheating and Thermal Cycling
- Bellow fatigue tests
- Operability tests under real solar conditions (Kontas at PSA, Spain)

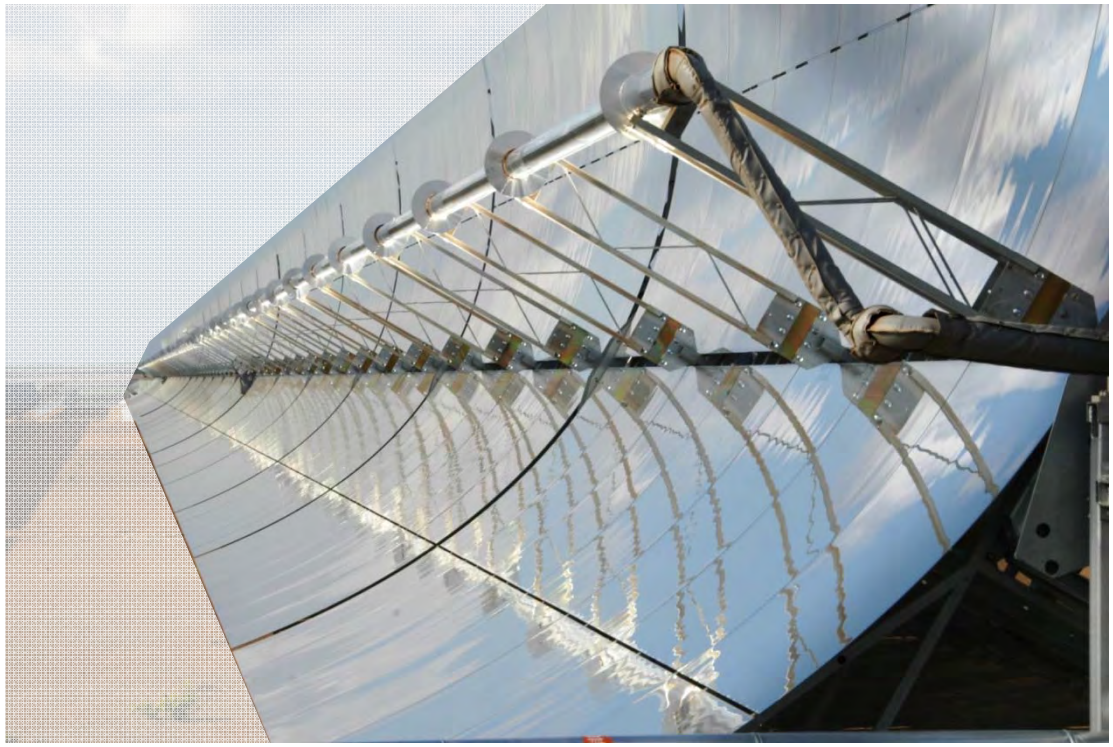
Performance testing – collector module





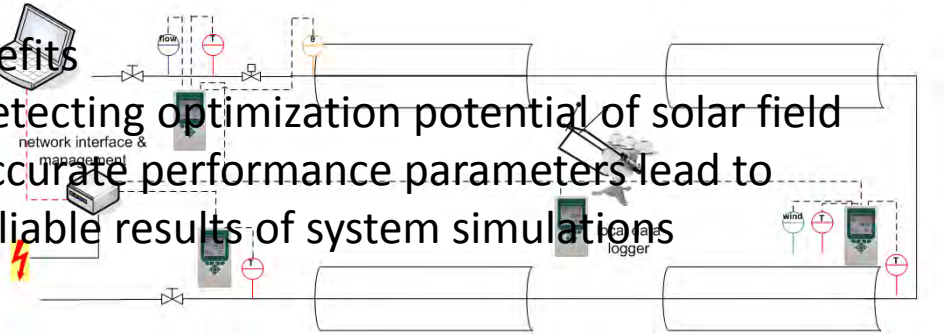
Collector quality features:
- Peak efficiency, thermal losses
- Incident angle modifier
- Behavior under different load conditions (tracking quality, deformation, torsion)

Performance testing – collector loop



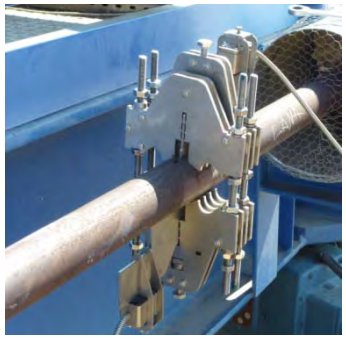
Mobile Field Laboratory:

- Clamp-on ultrasonic flow meter
- Clamp-on temperature sensors
- Irradiance measurement station
- Camera equipped quadcopter

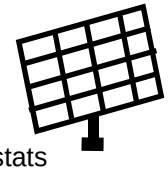
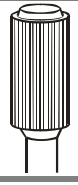


Benefits

- Detecting optimization potential of solar field
- Accurate performance parameters lead to reliable results of system simulations



Qualification in Different Phases

Phases Objects	R&D Phase Prototypes	Production Phase Mass Product	O&M Phase Commissioned Plant
Concentrator – Parabolic Trough Coll. 	✓	✓	✓
Concentrator – Heliostats 	✓	✓	✓
Receiver – Parabolic Trough Receiver 	✓	Several manufacturing specific quality control measures	✓
Receiver – Central Receiver 	✓	Several manufacturing specific quality control measures	✓
Materials	✓	Several manufacturing specific quality control measures	✓

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Summary
QUARZ – Benefits for our customers

- Detecting **optimization potential** helps to **improve products**
- Accurate performance parameters → **reliable results** of system simulations
- Source of **data** for a plant's **cost-benefit analysis**

- Customer oriented services

→ Fundamental information for industry to
  - **Improve** quality, performance → **competiveness**
  - **Proof** of product quality → successful **market entry / bankability**

- Trainings and Seminars
  in all CSP Relevant Topics



Summary (II)

Possible Cooperations

Meteorology / Solar Resource Assessment

- DNI, Sunshape, Soiling Rate, Beam Attenuation in Solar Towers

Solar Towers

- Receivers and Heliostats R&D, System Optimization

Qualification of Systems and Components

- Receivers, Heliostats, Collectors, Mirrors, etc.
- Production Inline Quality Control

Durability Issues of Mirrors and Receivers

- Ageing by UV Radiation and Corrosive Environments (Salts)

Capacity Building

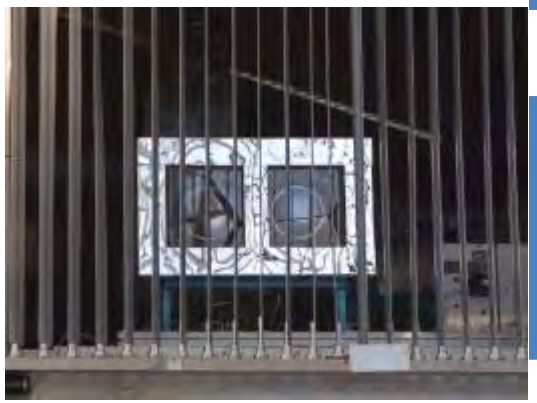
- Consulting and training in all CSP Relevant Topics

Department of Solar Chemical Engineering

Head
Organisation
Strategy
Representation in boards

Group
High temperature CE
Solar tower >500°C

Group
Low temperature CE
Reactors up to
Parabolic troughs
< 500°C



Solar Fuels
Solar Materials

Heat transfer fluids
Solar fuels
Water treatment
SOWARLA GmbH

25 Co-workers + 10 Students, 65% external funding

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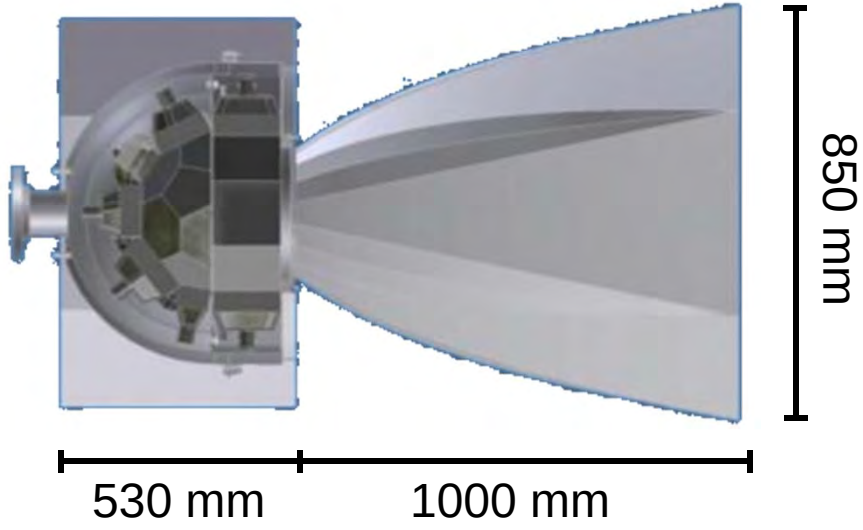
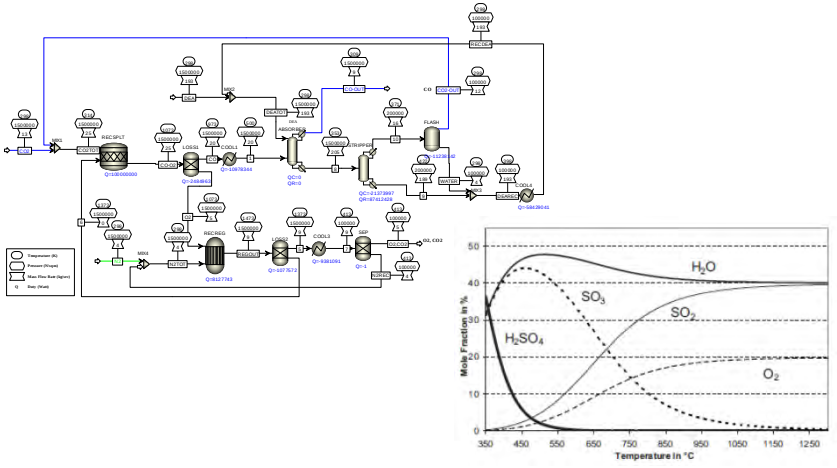
Competences

Development of components and processes

and

scientific, technologic and economic evaluation





Three examples to achieve the goals

- High Potential Product
  - Jet-Fuel

- Business Case
  - Integration of concentrated solar radiation to enhance existing processes

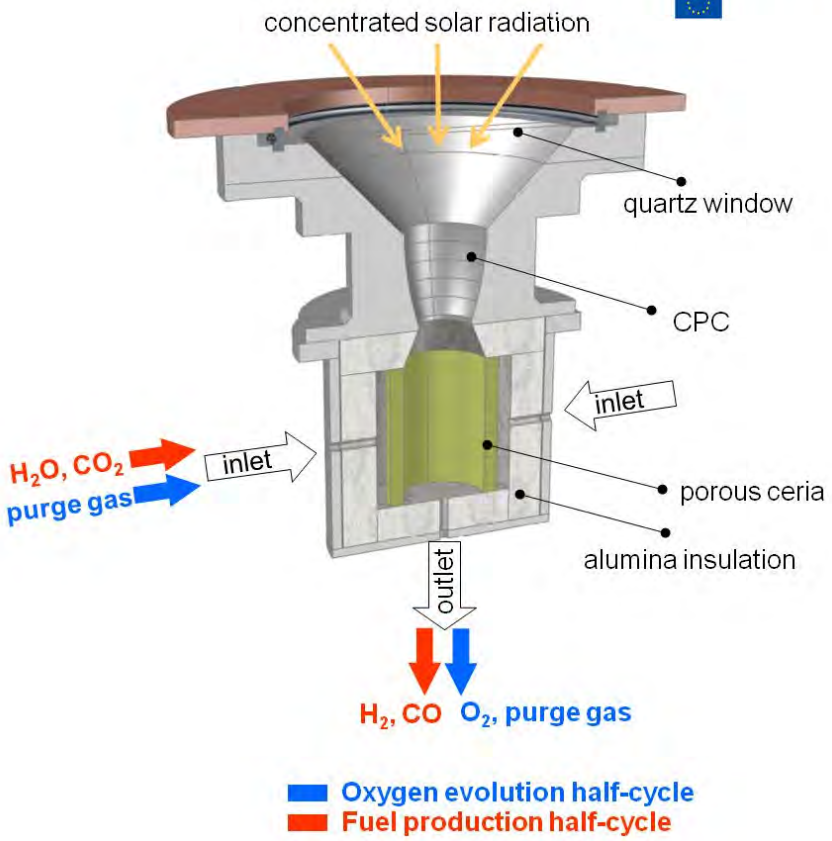
- Continuity
  - Developments to a certain scale needs time (unfortunately there is no Manhattan Project for solar fuels yet)

H_2O/CO_2-Splitting Thermochemical Cycles

SOLAR-JET
Zero-carbon jet fuel from sunlight

Solar Production of Jet Fuel

- EU-FP7 Project SOLAR-JET (2011-2015)
- SOLAR-JET aims to ascertain the potential for producing jet fuel from concentrated sunlight, CO_2, and water.
- SOLAR-JET will optimize a two-step solar thermochemical cycle based on ceria redox reactions to produce synthesis gas (syngas) from CO_2 and water, achieving higher solar-to-fuel energy conversion efficiency over current bio and solar fuel processes.
- **First jet fuel produced in Fischer-Tropsch (FT) unit from solar-produced syngas!**



Int. J. Heat & Fluid Flow 29, 315-326, 2008.
Materials 5, 192-209, 2012.

Partners: Bauhaus Luftfahrt (D), ETH (CH), DLR (D), SHELL (NL), ARTTIC (F)
Funding: EC

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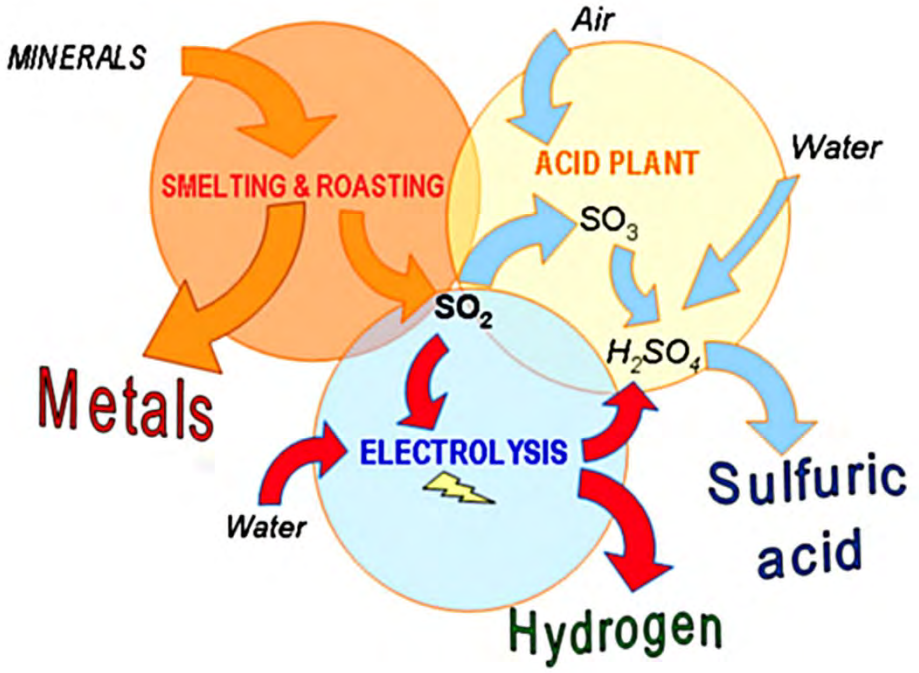
SOL2HY2 – Solar To Hydrogen Hybrid Cycles

https://sol2hy2.eurocoord.com

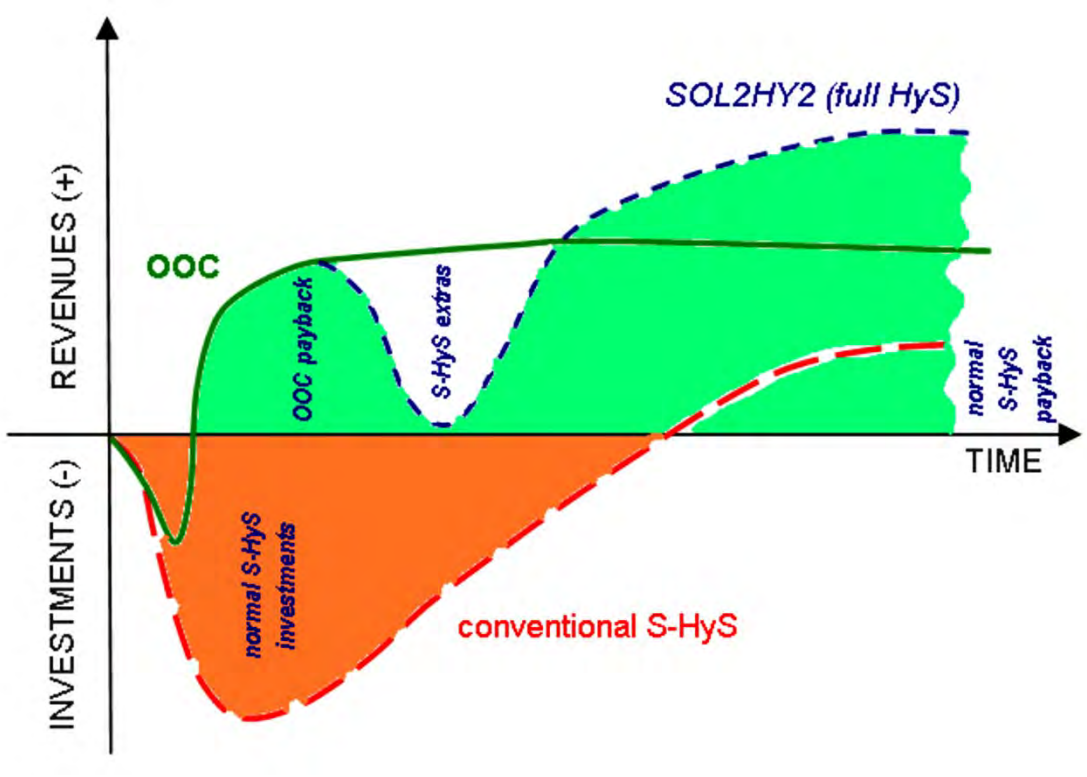
- FCH JU project on the solar driven Utilization of waste SO_2 from fossil sources for co-production of hydrogen and sulphuric acid
- Hybridization by usage of renewable energy for electrolysis
- Partners: EngineSoft (IT), Aalto University (FI), DLR (DE), ENEA (IT), Outotec (FI), Erbicol (CH), Oy Woikoski (FI)
- 100 kW demonstration plant on the solar tower in Jülich, Germany in 2015

Outotec™ Open Cycle (OOC)



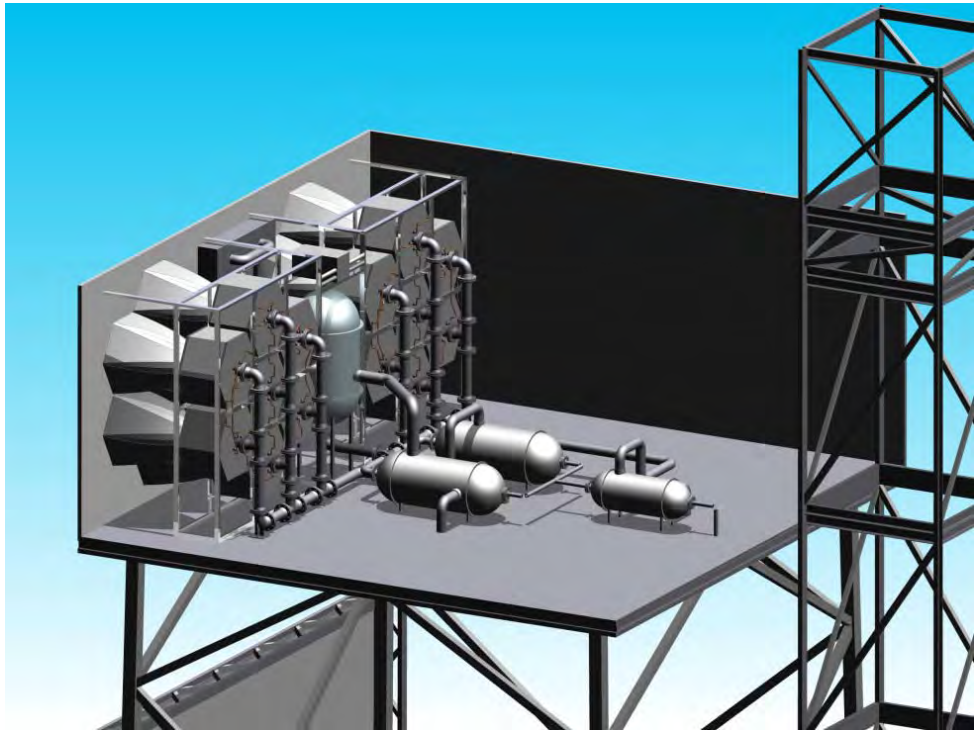
- Utilization of waste SO_2 from fossil sources
- Co-production of hydrogen and sulphuric acid
- Hybridization by renewable energy for electrolysis

Investments vs. revenues



- Reduction of initial investments
- Financing of HyS development by payback of OOC
- Increase of total revenues

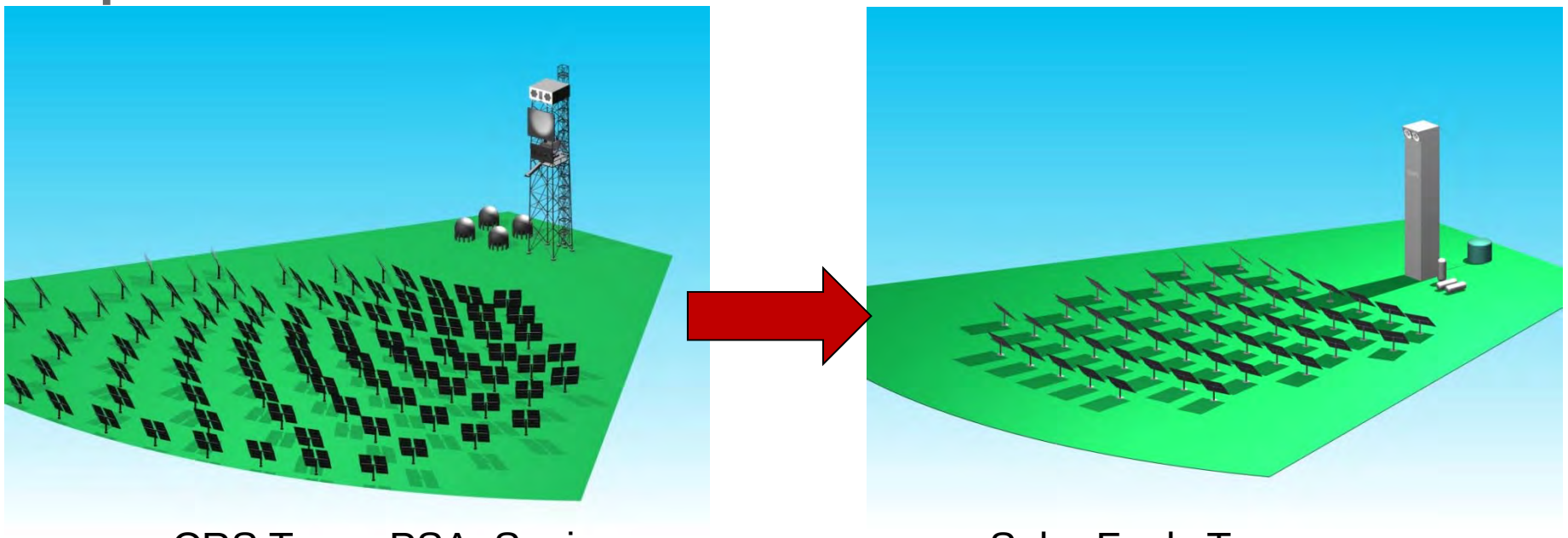
HYDROSOL, HYDROSLOL 2, HYDROSOL-3D, HYDROSOL Plant



- 2002 Start HYDROSOL, EU FP5
- 2004 First solar hydrogen, DLR
- 2005 Quasi-continuous solar hydrogen, DLR
- 2008 HYDROSOL 2, EU FP6, 100 kW demonstration CRS Tower PSA, Spain
- 2013 HYDROSOL-3D, FCH JU, Design of a 1,5 MW demonstration plant ready
- 2014 HYDROSOL PLANT, FCH JU
- 2015 750 kW Demonstration plant, CRS Tower, PSA, Spain

APTL (GR), DLR (DE), CIEMAT (SP), StobbeTech (DK), Johnson Matthey (UK), HyGear (NL), HELPE (GR)

Next Step:
Specific Solar Fuel Demonstration Tower needed!



CRS Tower PSA, Spain

Solar Fuels Tower

- High concentration > 1000
- Heliostats fit to receiver size
- Field control adapted to fuel production processes

Thank you very much for your attention!